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AUTHORITY

20040126 - target created b/3 to A/1

AD-B121 740

87-091RC0111GLA

LASER RANGE EVALUATION GUIDE FOR BIOENVIRONMENTAL ENGINEERS

JOHN E. BREWER, CAPT, USAF, BSC

July 1987

Final Report

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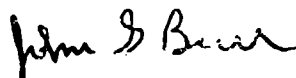
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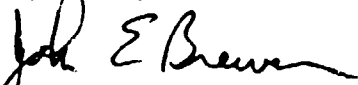
JOHN G. BURR, Lt Col, USAF, BSC
Chief, Radiation Services Division

Prepared By:

JOHN E. BREWER, Capt, USAF, BSC
Chief, Nonionizing Radiation Services

Approved By:

JOHN J. COUGHLIN, Colonel, USAF, BSC
Commander

B121 740L

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS N/A

2a. SECURITY CLASSIFICATION AUTHORITY N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT Distribution Statement B, see reverse
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	

4. PERFORMING ORGANIZATION REPORT NUMBER(S) 87-091RC0111GLA	5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION USAF Occupational and Environ- mental Health Laboratory	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS (City, State, and ZIP Code) Brooks AFB TX 78235-5501	7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING/SPONSORING ORGANIZATION Same as 6a	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code) Same as 6a	10. SOURCE OF FUNDING NUMBERS			
	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Laser Range Evaluation Guide for Bioenvironmental Engineers   (U)

12. PERSONAL AUTHOR(S)
John E. Brewer, Capt, USAF, BSC, Ross Murray, Capt, USAF, BSC, Burl H. Olson, 1Lt, USAF, BSC

13a. TYPE OF REPORT Final	13b TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day) July 1987	15. PAGE COUNT 108

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Laser Range Safety, Laser Range Hazards, PAVE SPIKE
			Laser Footprint, Designators PAVE KNIFE
			Range Finders, PAVE TACK TRAM

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The USAFOEHL/RZ was requested by AFOMS/SGPR to develop a guide to assist base level Bioenvironmental Engineers in establishing safe range lasing operations. This report contains descriptions of potentially hazardous situations and the needed range safety controls. In addition, evaluations of lasers, both airborne and ground, of the systems currently being used throughout DOD are included. (Keywords;

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL BREWER, JOHN E., Capt, USAF, BSC	22b. TELEPHONE (Include Area Code) (512) 536-3486	22c. OFFICE SYMBOL USAFOEHL/RZ

DD Form 1473, JUN 86   Previous editions are obsolete.   SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Item 3 continued

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ACKNOWLEDGMENTS

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I. INTRODUCTION

The use of lasers in tactical aircraft and by ground personnel on Air Force controlled weapons ranges has increased dramatically in the past decade. Because of the potential for eye and skin injuries from these lasers, Bioenvironmental Engineering Services (BES) personnel are required to perform laser hazard evaluations and recommend control procedures prior to their use on weapons ranges. Unfortunately, because of limited experience with lasers, most BES personnel must rely on other organizations (example: USAFOEHL) when performing their range evaluations. The assistance provided may fulfill the requirements stated in AFOSH Standard 161-10, Health Hazard Control for Laser Radiation, and AFR 50-46, Weapons Ranges, but does not necessarily provide the training or education needed by BES personnel to ensure that everyday range operations are indeed safe. This report is intended as an interim instructional guide on range procedures and their application. To be released concurrently with this guide, is a Z-100 and IBM PC compatible laser hazard evaluation computer program, laser range footprint calculation program, and a laser sources inventory program. Eventually, a DOD range evaluation manual will be published. Additionally, the Air Force Engineering Services Center is developing a Z-100 compatible computer program to perform some of the evaluations presented in this guidebook. Their program will contain specific details about each range, and generate a hazard plot on a map.

This guide incorporates ANSI Z136.1, American National Standards for the Safe Use of Lasers, and Tri-Service procedures as directed by Air Force Office of Medical Support to initiate uniformity in DOD laser range evaluations. To facilitate this, the following terms are now used: laser class, rather than laser category (CAT); nominal ocular hazard distance (NOHD), rather than safe eye exposure distance (SEED); and laser surface danger zone (LSDZ), rather than hazard zone. This guide supplements AFOSH Standard 161-10.

The procedures and mathematical equations for performing a laser hazard evaluation to determine laser classification, NOHD and degree of protection required (Optical Density - OD) are in AFOSH Standard 161-10, and will be available as a Z-100 compatible computer program. Therefore, they are not examined in detail in this report. In an effort to ensure that all BES personnel are using consistent laser system hazard parameters, this report contains hazard evaluations for both airborne and ground lasers presently being used by DOD forces on Air Force weapons ranges. These can be found in Appendices A and B.

II. BACKGROUND

Most lasers presently used in tactical military applications are either range finders or designators. The majority are pulsed lasers and radiate in the near infrared spectrum (700-1400 nanometers). Laser classification, NOHD, and OD required are usually well defined and will not vary from weapons range to weapons range. The variables of usual concern in laser range evaluations are the range itself (size, topography, etc.), personnel operating the

laser (Air Force, Army, Navy, Reservists, etc.) and the mission (air-to-ground, ground-to-ground, etc.). To assist BES personnel in performing a range evaluation, a step-by-step procedure is presented in this report.

III. RANGE EVALUATION PROCEDURE

A laser range evaluation can be performed for a specific laser system or for a general class of lasers. The latter is recommended if available land permits and the mission is not severely impacted. To perform this general evaluation, the worst case conditions of all possible systems and missions are used. If this is too restrictive, separate evaluations for each system must be performed. In order to simplify the range evaluation procedure we divided it into five steps: The laser; the range; the target; the mission; and the laser surface danger zone.

A. **The Laser**: To evaluate a laser it is necessary to determine the hazard potential of the system. This is accomplished by determining the following:

1. Maximum Permissible Exposure (MPE) Limits: Determine the applicable MPE for the laser being evaluated.

2. Laser classification: Classify the laser using procedures in AFOSH Standard 161-10, and MIL STD 1425, 13 Dec 83, Safety Design Requirements for Military Lasers and Associated Equipment, to determine what laser control procedures are required (interlocks, warning labels, etc.).

3. Nominal Ocular Hazard Distance (NOHD): Calculate the distance from an operating laser to the point where it is no longer an eye hazard using procedures in AFOSH Standard 161-10, previously calculated data, previously measured data, or Appendices A and B. There are four types of NOHDs. They are single pulse NOHD (NOHD-S), multiple pulse NOHD (NOHD-M or simply NOHD), diffuse reflection NOHD, and NOHD for optically-aided viewing (NOHD-O). Additionally, if the laser emission can exceed the skin MPE, a Nominal Hazard Distance (NHD) is possible for skin.

4. Diffuse reflections: Determine if the laser is capable of producing hazardous diffuse reflections (Diffuse Hazard) using procedures in AFOSH Standard 161-10, previous evaluations, or Appendices A and B. Lasers which can produce hazardous diffuse reflections are classified as ANSI Class 4 and have a diffuse reflection hazard distance (t) associated with it. It is unusual for field type lasers to produce diffuse hazards (presently, only the M60 Tank and the M551 A1 Sheridan Vehicle produce hazardous diffuse reflections). Normally for a diffuse hazard, the beam path up to the NOHD or point of termination (if less than NOHD), is a denied occupancy area and no objects are permitted in the beam path.

5. Optical density (OD): The degree of protection (opacity) required to reduce the incident laser energy to safe eye and skin levels must be calculated. (See AFOSH Standard 161-10.) These are also available in Appendices A and B, or previous evaluations.

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6. Optical viewing: Consider the possibility of personnel viewing the beam, or reflections of the beam, through optical instruments (binoculars). The light-gathering ability of the optics can significantly increase the degree of hazard for the eyes (increase OD and NOHD). Procedures to evaluate this are in AFOSH Standard 161-10. Some evaluations are included in Appendices A and B.

7. Atmospheric attenuation: Atmospheric attenuation can be quite high for infrared lasers operating over distances of 10 kilometers or greater. It can reduce the NOHD considerably and should therefore be included in the laser evaluation. To aid in many evaluations a set of footprint tables for the PAVE SPIKE and PAVE TACK systems which use an atmospheric attenuated NOHD are included in Appendix D in addition to the tables which use the vacuum NOHD. This set of footprint tables based on atmospheric attenuated NOHD are only valid for lasing from altitudes below one kilometer (km) above mean sea level (MSL). If flight profiles include lasing from altitudes above one km, new site specific tables should be generated using the USAFOEHL footprint computer program or the tables in Appendix D based on the vacuum NOHD. As a last resort, footprint dimensions can be manually calculated using the procedure listed in AFOSH Standard 161-10 or Appendix G.

8. Laser platform stability: The stability of the laser platform must be evaluated to determine pointing accuracy of the laser system. The pointing accuracy will determine the size of the buffer angle. The largest buffer angle for airborne (aircraft) or ground based stable platforms (tripods) is 5 milliradians, while hand-held lasers require 10 milliradians (Note: this is a recent policy change from 15 milliradians). Section III.E describes the procedure for determining the buffer angle.

B. The Range: Both a range map and topographic map of the area are needed for the laser range evaluation.

1. Range map: The range map is essential in order to establish accurate distances from target area to range boundaries. The range map should have the boundaries and include geographic items such as roads, streams, ponds and rivers. All man-made improvements such as towers, buildings, etc., should also be on the map. Boundaries of special purpose areas such as an airstrip and the location of targets are also required.

2. Topographic map: The topographic map is important because it enables the evaluator to determine the elevation of the target area relative to the surrounding terrain. It is important that no portion of the beam which exceeds the MPE limits extend beyond the controlled area. This can be accomplished by utilizing natural geographic backstops such as hills. A topographic map is very helpful in identifying these backstops and in repositioning targets if necessary.

3. Airspace: Normally, "controlled airspace" is that airspace directly over the range up to a specified altitude. It is important that this controlled airspace and exceptions are made known. Lasing is not normally authorized outside the controlled airspace or when other aircraft are between the laser and the target. Also, if the beam is directed up, or if hazardous

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reflections could exceed the height of the controlled airspace, additional controls may be necessary. See Section III.E.3.b for more information.

C. **The Target**: The size, location, and type of targets to be lased on a range are of primary importance in determining the hazard zone.

1. Optimum target: The optimum target from a safety point of view is a nonreflective surface. Flat specular surfaces must be removed or covered because reflections from them can retain high collimation. A flat specular surface is one in which you can see a relatively undistorted image. Examples of specular surfaces are windows, Army tank vision blocks, search light cover glass, plastic sheets, glossy painted surfaces, still water, clean ice, flat chrome, and mirrors. Snow is not a specular surface, but if thawed and refrozen, hazardous reflections can be found, especially at low angles of incidence. Glossy foliage, raindrops, and other natural objects are not hazardous targets. These and most other curved surfaces may be specularly reflective, but the reflected irradiance (energy per unit area) decreases quickly with distance. This is because the beam spreads as a function of the radius of curvature of the surface. The only exception to this is concave reflective surfaces. These can focus the reflected beam and cause the reflection to be more hazardous than the incident beam. Practically, these reflections are of little concern since it is improbable that the surface is perfectly concave (focuses the beam to a single point) or perfectly reflec- tive. Additionally, the focus point(s) would probably be very close to the object (small radius of curvature) and be of little concern since people don't normally put their head close to objects and if they did, they would probably block the incident beam. Concave surfaces with a large radius of curvature which could focus at longer distances would appear nearly flat and be covered. These four types of reflections are detailed in Figure 1. Further information is provided in Appendix F.
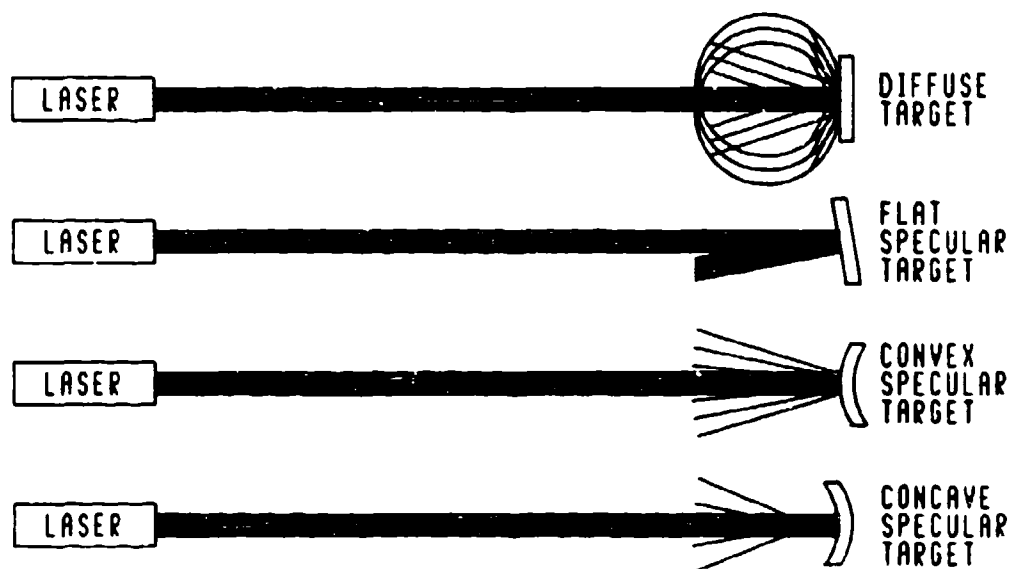
FIGURE 1. DIFFUSE REFLECTION AND SPECULAR REFLECTION

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2. Size and location: The number and location of targets (distribution) will affect the size of the hazard zone. On ranges with limited space it is important that all targets be as close together as tactically feasible.

D. **The Mission:** An evaluation must be accomplished for each type of laser used on the range. The lasing mode, e.g., air-to-ground, ground-to-ground, etc., must be determined. At the present time, air-to-ground and ground-to-ground are the normal modes used by tactical forces. In the near future, training exercises will include the ground-to-air mode as more state-of-the-art airfield and ground force air defense systems are developed. The air-to-air mode is used for R&D projects and then only with special permission. Required information is listed below for each case.

1. Air-to-ground: Determine desired flight profiles. Information necessary to perform an evaluation are the altitudes, ranges, and directions of the aircraft, relative to the target, when lasing. Various terms are used to describe the aircraft direction during ordinance delivery, they include: approach track, attack heading, and run-in heading. These headings can be on a single bearing, a range of bearings, and unrestricted approach (360°). Typical mission profiles are:

    a. Toss Delivery, General Profile:

       Slant Range: 1,800-70,000 feet (0.3-11.5 nautical miles)
       Altitude: 200-2,600 feet

    b. Toss Delivery, Mode A:

       Slant range: 20,000-70,000 feet (3.3-11.5 nautical miles)
       Altitude: 200-320 feet

    c. Toss Delivery, Mode B:

       Slant Range: 10,000-25,000 feet (1.6-4.25 nautical miles)
       Altitude: 1,000-3,400 feet

    d. Straight and Level Delivery:

       Slant Range: 1,800-30,000 feet (0.3-4.8 nautical miles)
       Altitude: 1,500-3,300 feet

    e. Dive Delivery:

       Slant Range: 8,500-14,000 feet (1.4-2.3 nautical miles)
       Altitude: 4,000-7,600 feet

2. Ground-to-ground: Determine possible laser locations and direction of lasing.

E. **Laser Surface Danger Zone (LSDZ):** Formerly called the hazard zone in the 1980 version of AFOSH Standard 161-10, the LSDZ is defined as a designated region in space where the probability of exposure to laser radiation is

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greater than that determined to be safe. The LSDZ considers botn direct hazards (main beam) and indirect hazards (reflections). The boundaries of the LSDZ depend on which of the two overlapping zones, direct hazard zone or the indirect hazard zone, is larger. If there are no specular reflectors in the range and the laser is not a diffuse hazard there will not be an indirect hazard zone. The direct hazard zone will always exist if laser to target distance is less than the NOHD. The LSDZ includes the laser beam plus a buffer zone around the beam to account for laser platform instability. There are three types of LSDZs. The total hazard zone is called LSDZ area Z or simply the LSDZ. The area that must be cleared of specular surfaces is called LSDZ area S. For airborne lasing, it is the same as LSDZ area Z. For ground based lasing from elevated platforms where the laser projects a well defined footprint, it should equal LSDZ area Z. For ground based lasers that do not project a well defined footprint in the target area, LSDZ area S is usually defined by a circle of radius S (as specified in Appendix B of this report) around the target. Backstop areas where the energy of the incident beam is capable of producing a specular reflection hazard are also considered LSDZ area S. LSDZ area T is the diffuse reflection hazard zone, it extends to distance t, the diffuse reflection hazard distance, and will only be present for lasers capable of producing a hazardous diffuse reflection (these have a distance t associated with them). LSDZ area T is considered an exclusion zone, no one is allowed in it and nothing should be lased in it. Although a skin hazard can also be in this area, this is considered a minor concern compared to the diffuse reflection hazard.

1. **Airborne lasers**: Calculate the size of the beam which irradiates the ground (footprint). Normally, laser beams are circular, diverge equally in all directions, and produce cone shaped beams. The size of the beam depends on the initial beam diameter, divergence, and distance (slant range) from the source. The size of the footprint is the size of the beam plus a buffer zone. For scanning systems, the size of the beam would include all positions in the scan. The shape of the footprint depends on the angle of the beam which intersects the ground (slant angle is determined from the range and altitude). The footprint is determined by the following:

a. Determine the buffer angle: To perform an evaluation which would be adequate for most airborne lasers use 5 milliradians for the buffer angle and ignore the beam divergence since most divergences are less than 0.5 milliradians. This approach will only introduce an error of less than 5%. If this evaluation is overly restrictive (requires too much land), a system specific evaluation can be made for each laser system. The appropriate buffer angles for most systems are listed in Appendix A. To calculate a buffer angle for other systems, perform the following: When the beam divergence is equal to or greater than 1.0 milliradian, the buffer angle will be five milliradians. When the beam divergence is less than 1.0 milliradian, the following will apply:

(1) If the aiming accuracy is unknown, the buffer angle will be five milliradians.

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(2) If the aiming accuracy is known, the buffer angle will be five milliradians or the absolute value of the aiming uncertainty (in milliradians) plus five times the beam divergence at the 1/e (.3679) point, whichever is less. Aiming accuracy should be contained in the system specifications.

b. Determine footprint size: There are at least two approaches used to determine the size of the footprint. If the desired flight profiles are known then the size of the footprint can be determined from these flight profiles. If the size of the range is the limiting factor, the boundaries of flight profiles can be determined which would keep the footprint within the range. These two approaches can be used independently or, typically, used together to maximize land use and minimize mission impact. The procedures for these two approaches are detailed below.

(1) To determine footprint size from predetermined flight profiles:

(a) Initially: Use the footprint tables in Appendix D to determine the footprint size from the range of flight profiles provided. These tables are based on the multiple pulse NOHD without the aid of optics. If it is possible for the laser to be viewed with optics, the NOHD for optically-aided viewing should be used. For most cases, the largest footprint is made with the longest slant range and lowest lasing altitude combination. Note that two sets of footprint tables for specific systems are provided. One set is based on the NOHD in a vacuum and the other set is valid if all lasing will be performed at altitudes below one km MSL. Additionally, Table D.5 is provided which can be used for any airborne laser system. Table D.5. is very conservative. If these tables do not cover your case, the dimensions can be calculated. The basic calculation procedure is provided in Appendix C. A computer program to make your own footprint charts using these procedures is available from USAFOEHL. These tables and calculations assume flat terrain. Corrections for terrain will come later.

1. We start the footprint determination procedure by using the following diagram to illustrate a footprint (Fig 2). Incidently, this diagram and the following diagrams are not drawn to scale in order to be easier to read.
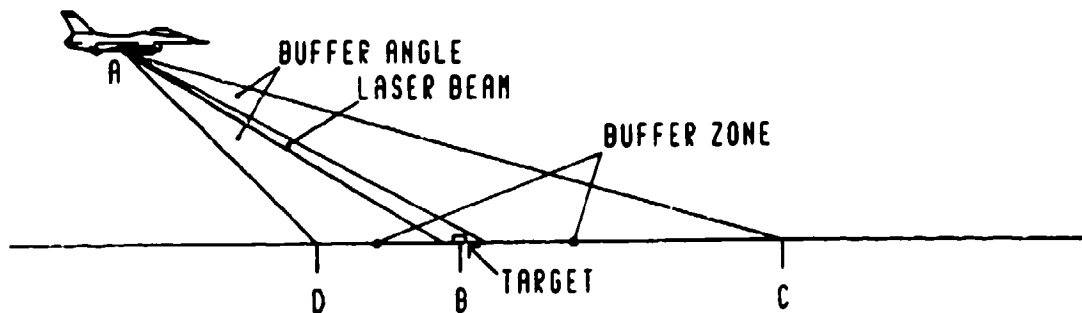
FIGURE 2. LASER FOOTPRINT WITH SINGLE TARGET

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    2.   Figure 2 assumes that the target is small. If the target is large, or multiple targets are present in an area, the diagram would be misleading. Therefore, the diagram in Figure 3 expands the beam position to account for a large target area. For a scanning laser system, the target area shown below would be the scanned areas, while the remainder of the area from D' to C' would be the buffer zone around the scanned area.
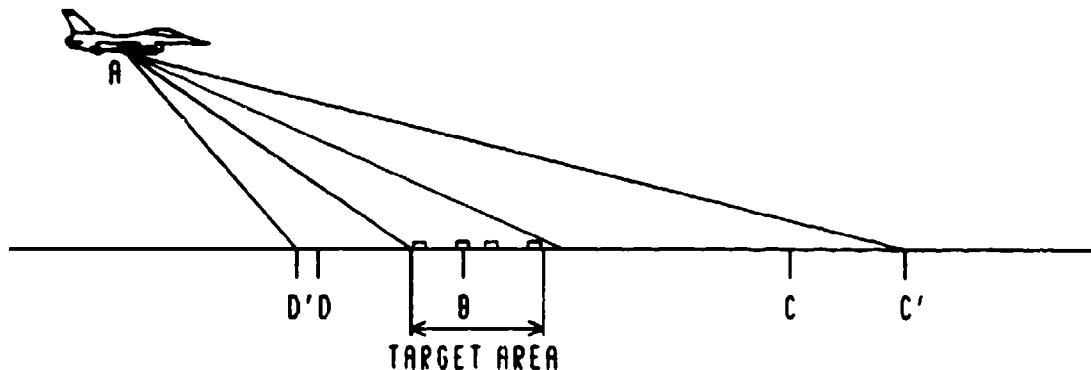
FIGURE 3. LASER FOOTPRINT WITH MULTIPLE TARGETS

    3 The shape of the laser footprint on the ground is an ellipse as shown in Figure 4. This footprint will determine where LSDZ area Z, or the hazard zone is.
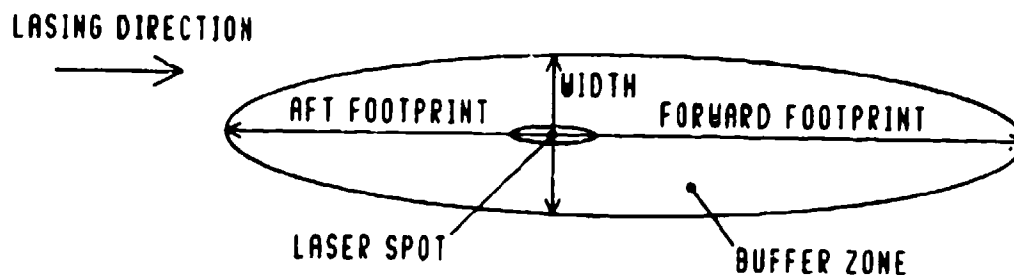
FIGURE 4. LASER FOOTPRINT

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4. If the attack will only be from one direction, and the laser only fired straight ahead, the LSDZ area Z will be the size of the largest footprint dimension calculated. It can be represented as a rectangle or as an ellipse as shown in Figure 5. Normally a rectangle is used for these evaluations. The dimensions of which are listed as forward, aft, and width dimension in the footprint tables.

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AFT FOOTPRINT | WIDTH | FORWARD FOOTPRINT

LSDZ AREA Z
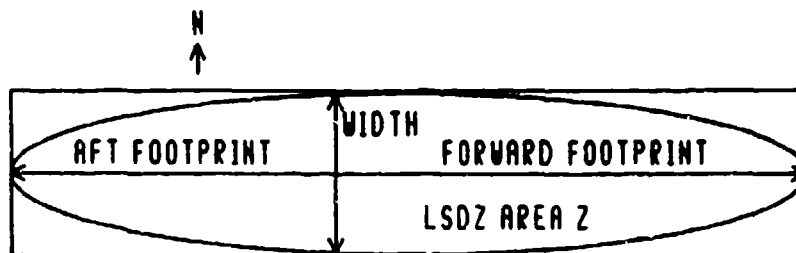
FIGURE 5. LSDZ - ATTACK BEARING 90 DEG

5. If the attack (or lasing) will be from a range of bearings, the LSDZ will be a summation of all possible footprints. This results in a LSDZ in the shape of two, pie-shaped sections. The length of these will be equal to the forward and aft footprint dimensions. The width of these pie-shaped sections will be the extremes of the attack bearings plus half the dimension of the footprint width. This is illustrated in Figure 6.

N
↑

WIDTH

AFT FOOTPRINT | FORWARD FOOTPRINT

LSDZ AREA Z
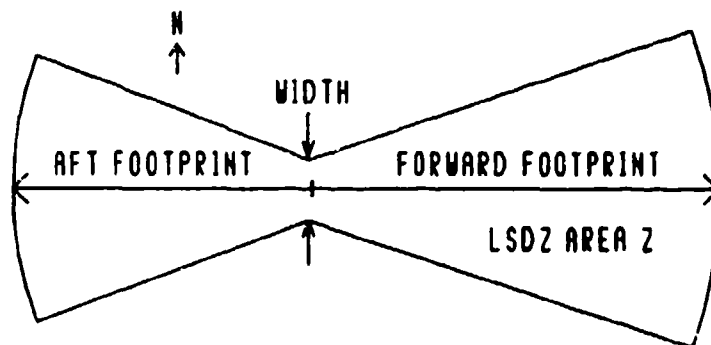
FIGURE 6. LSDZ - ATTACK BEARING 70 TO 110 DEG

6. If the attack bearings are not specified or attack from any direction is desired, the LSDZ will be a circle with a radius equal to the longest forward or aft dimension listed in the footprint table for the possible altitudes and slant ranges. This is illustrated in Figure 7.
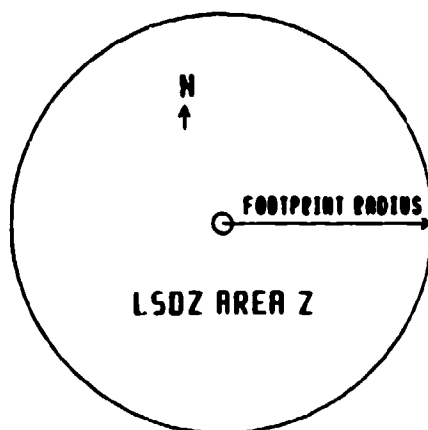
FIGURE 7. LSDZ - ATTACK FROM ANY DIRECTION

7. As a way of application, if the conditions of the three cases described above were based on the PAVE SPIKE laser fired from 200- 1000' above ground level (AGL) at ranges of 1-4 nautical miles, the longest dimensions, based on these flight profiles, are 8,500' forward, 5,960' aft, and 130' wide (see PAVE SPIKE Footprint Table D.1 in Appendix D). If the elevation were to include all types of laser systems, with the above flight profiles, the footprint dimensions would be 37,600', 9,190', and 243', respectively (See table, D.5. in Appendix D).

8. If the target and area covered by these footprint dimensions are on level ground, and no specularly reflective surfaces are present, the LSDZ or hazard zone is the size of the LSDZ determined above.

(b) If the terrain is not level: Determining footprint dimensions can get rather involved. Actual procedures vary case by case but, the following suggested general procedures are presented for common conditions. Some specific examples are shown in Appendix E.

1. Target area on rising terrain: This condition is of little concern because it makes the calculations performed above conservative. If overly conservative, the footprint dimension can be reduced. See Figure 8 for clarification.
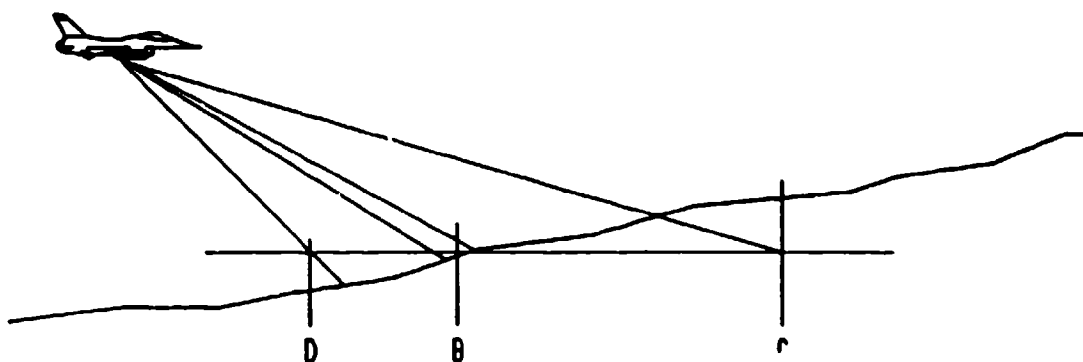
FIGURE 8. LSDZ WITH RISING TERRAIN

2. Natural Backstops: Hills behind the targets can reduce the size of the footprint as rising terrain did above. Additionally, accidental reflections and misdirected beams can be contained within the range. Effects of correct and incorrect target location and flight profiles are illustrated in Figures 9 and 10.
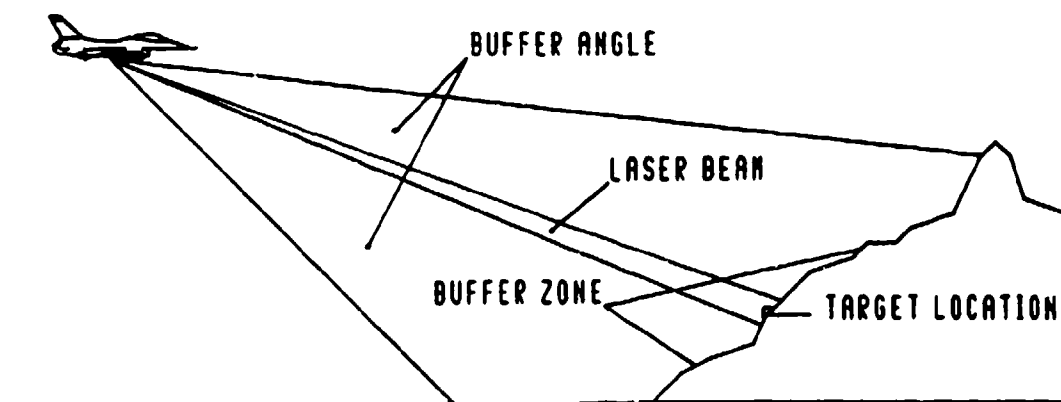
FIGURE 9. USE OF NATURAL BACKSTOPS TO CONTROL LASER BEAM

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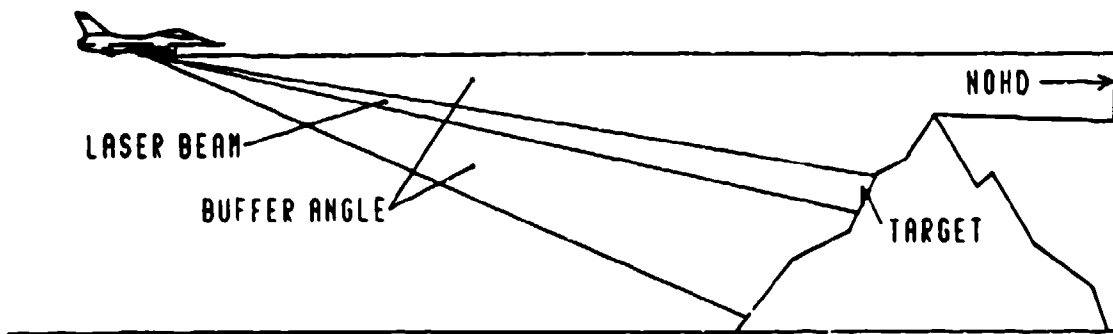
FIGURE 10. INSUFFICIENT BACKSTOP TO CONTROL LASER BEAM

      3. Falling terrain in target area (or hills in the foreground): This condition requires some modifications to the previously calculated dimensions.

      a. For the foreground: The height MSL, or height AGL, reference to the target of the bottom laser beam path (line AD) must be determined for all distances between the laser and target. A method of doing this is to calculate the height of the beam from the slant of AD. The slant of AD is approximately equal to the altitude divided by the difference of slant range and aft footprint dimensions. Then, these elevations are compared to the terrain height under the laser beam for all attack angles. This condition is illustrated in Figure 11.
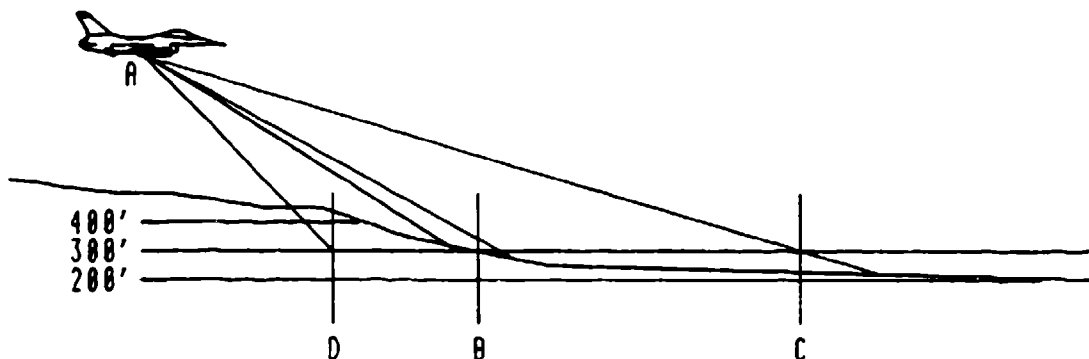
**FIGURE 11. LSDZ WITH TERRAIN SLOPING DOWN
RANGE < NOHD, TARGET AT 300' MSL**

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b. For the ground beyond the target: This
condition can greatly extend the forward footprint dimension as illustrated in
Figure 11. If flight profiles are not limited, the forward footprint could be
as long as the NOHD as illustrated in Figure 12.
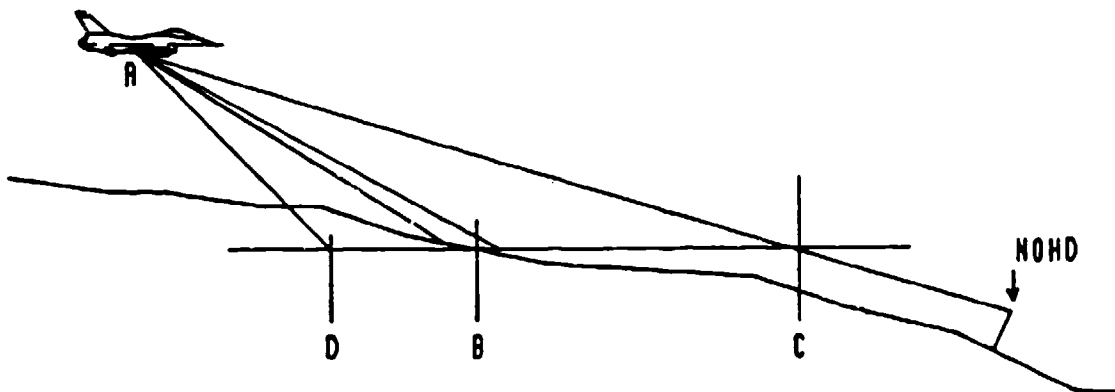
FIGURE 12. LASER SURFACE DANGER ZONE WITH TERRAIN SLOPING DOWN
          RANGE > NOHD

          (c) Specular reflections: If the area in the footprint
can be cleared of all flat specular surfaces, then the LSDZ is the size
calculated above. If flat specular surfaces are within the LSDZ Area Z, these
should be removed, covered, or painted. If they can't be effectively removed,
the LSDZ Area Z may need to be expanded by the procedures in the following
sections. Normally the LSDZ is expanded out to the single pulse NOHD (NOHD-S)
rather than the multiple pulse NOHD (NOHD) when accounting for reflections.
This is because the probability of multiple pulse exposures is very remote
when the angle of attack, relative to the target is changing rapidly. When
the angle of attack is not changing rapidly, as when lasing from long
distances, the multiple pulse NOHD should be used. In actual practice when
both NOHDs are used over a range of lasing distances, the NOHD-S at close
ranges will give the most conservative result. In addition, if it is possible
for the laser beam to be viewed with optics, the NOHD for optically aided
viewing should be used.

          1. Still water: Determine if the reflection from
this surface can enter uncontrolled airspace or hit a hill beyond the range
boundaries. These are illustrated below in Figure 13. If these are not a
problem, no further controls are necessary. If this appears to be a potential
problem, limit the flight profiles, move the target, or control more land or
airspace. See Appendix F for more information on reflections.

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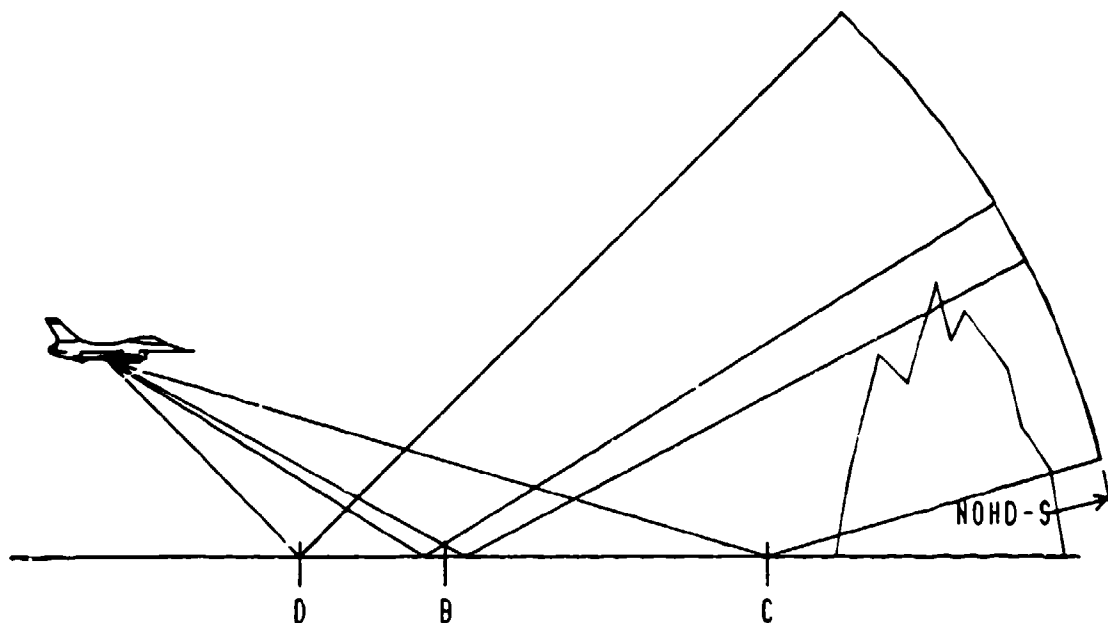
FIGURE 13. REFLECTIONS FROM STILL WATER WITHIN THE LSDZ

2. Flat specular surfaces on or near target: Aircrew, ground personnel, and the surrounding community need to be considered for this condition. If the reflectivity of the specular surfaces is known the effective NOHD can be reduced by (approximately) the square root of the reflectivity coefficient. See Appendix F for more information.

a. Aircrew: Present Air Force policy requires aircrews to wear laser protective eye wear when: flying in multiple ship formations, targets are not clear of specular surfaces, and ground based lasers are used against the aircraft. If the target area is not clear of specular surfaces, and the aircrews lase from distances less than one-half of the NOHD, aircrews are at risk of eye damage if eye wear is not used. This and other possible exposure situations are illustrated in Figure 14.
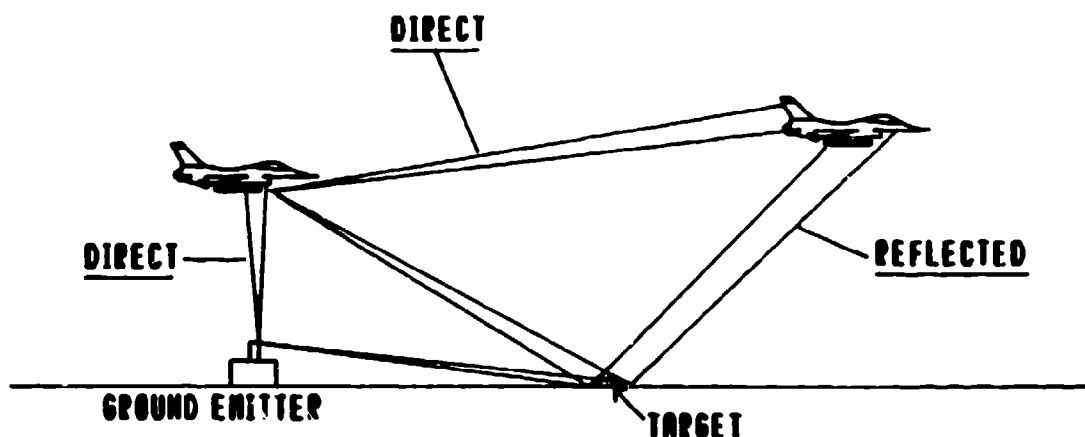
FIGURE 14. POTENTIAL EXPOSURE MODES

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b. Ground personnel and surrounding community:
If flat specular surfaces are near the target, the laser beam can be redirected in any direction as shown in Figures 15 and 16. Therefore, the LSDZ should be extended to a circle with a distance equal to the NOHD minus the minimum lasing distance. As with the cases described above, natural backstops and terrain may alter the shape of this area. Additionally, airspace over the range may be at an unacceptable risk. This is similar to the condition described above for standing water.
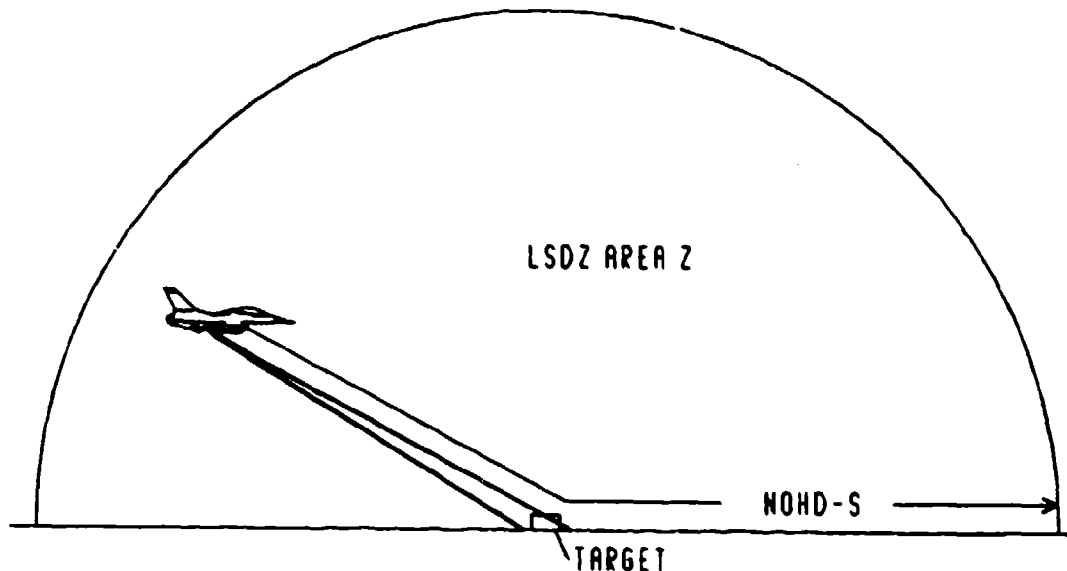
FIGURE 15. REFLECTIONS FROM FLAT SPECULAR SURFACE, SIDE VIEW
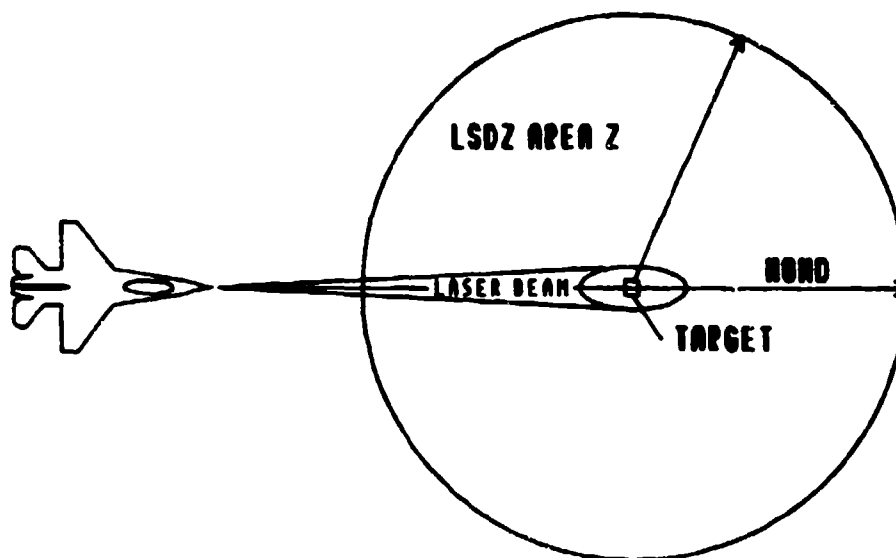
FIGURE 16. REFLECTIONS FROM FLAT SPECULAR SURFACE, TOP VIEW

15

(2)   If the range is small and therefore is the controlling factor, we usually determine the flight profiles from the land size as follows:

        (a)   Determine desired target location.

        (b)   Draw outline of controllable range area.

        (c)   Measure distance from target to range boundaries.

        (d)   Use footprint tables or calculate flight profiles which would not cause the LSDZ to exceed the range boundaries. Procedures for this are a modification of the procedures of Section III.E.1.b.(1) above.

    2.   <u>Ground Based Lasers:</u>   Ground-to-ground laser target designators and range finders are used by the Army and Marines on Air Force ranges. They are either classified as ANSI Class 3 or 4. If Class 4, hazardous diffuse reflections are possible. For these Class 4 lasers, three "hazard zones" are present. LSDZ Area S is normally the area around the target area and backstop. The size of these areas has been predetermined by the Army (or major owning service) and is listed in Appendix B. LSDZ Area Z is the area contained within the NOHD or natural backstop. LSDZ Area T is the area out to t (the diffuse reflection hazard distance). No objects are to be lased in this area because hazardous diffuse reflections are possible. Personnel are also excluded from this area because the incident laser beam's intensity usually exceeds the skin MPE. For Class 3 lasers, only LSDZ Area S and LSDZ Area Z are present. The procedures for evaluating these missions are detailed below.

        a.   Determine the buffer angle: The procedure for determining the buffer angle for ground-to-ground lasing is the same as air-to-ground unless the laser is hand-held. For hand-held lasers, the buffer angle will be 10 milliradians. Remember that this buffer angle is used for a horizontal and vertical buffer angle.

        b.   Determine the LSDZ:

        (1)   Normal procedures for evaluating ground based laser operations are detailed below. However, if lasing is to be performed from an elevated platform where the laser beam projects a well defined footprint, it should be evaluated using the procedures detailed above for airborne lasers.

        (2)   If the terrain is flat or falls off in the distance (no backstop): The LSDZ will be a cone extending out to the NOHD and cover an arc which covers the target area plus a buffer angle as illustrated in Figure 17. The width of the arc is chosen to allow lasing at any target and any point on the targets in the target area. If the targets are separated by great distances and the laser would not be used to sweep between targets, separate arcs could be established for each target.

16
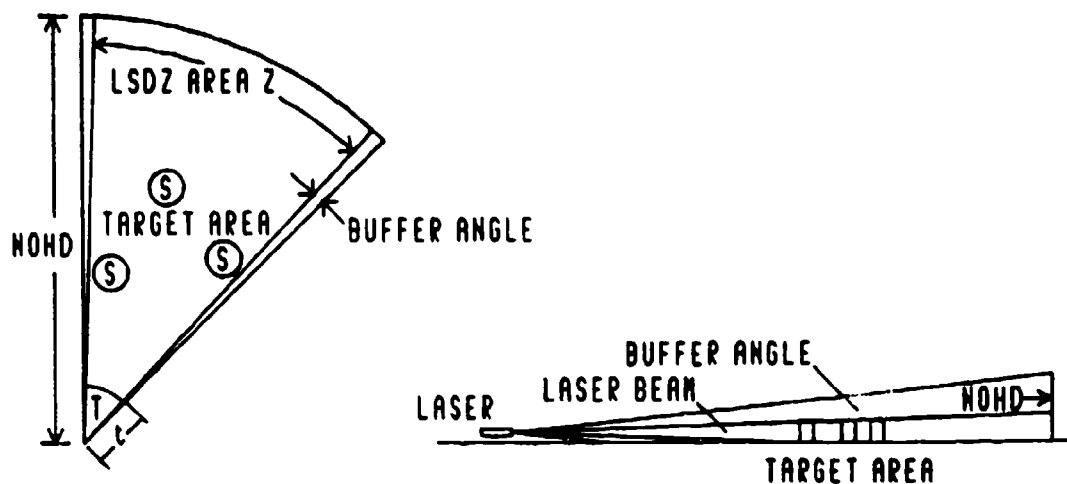
FIGURE 17. LSDZ FROM GROUND FIRED LASER - WITHOUT NATURAL BACKSTOP

(3) Terrain with natural backstops: If the beam is termina-
ted by natural backstops within the NOHD, then the LSDZ is contained in that area.
Ensure that the terrain is high enough to include the buffer angle. Figure 18 will
clarify these points.
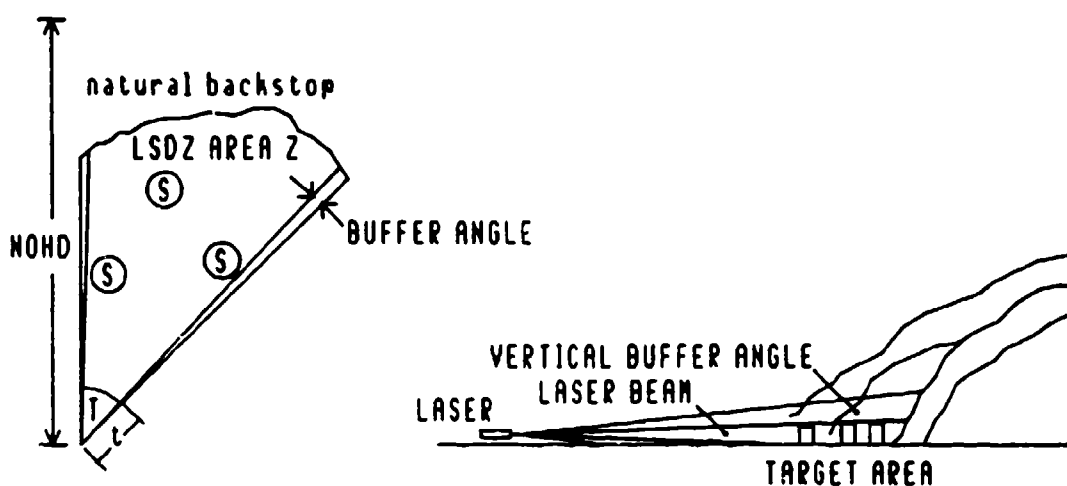
FIGURE 18. LSDZ FROM GROUND FIRED LASER - WITH NATURAL BACKSTOP

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(4) Specular reflections: Normally, only the LSDZ area S and backstop areas are cleared of specular surfaces. If these areas cannot be cleared of specular reflectors, conditions as described in the air-to-ground section above need to be considered. These conditions include the laser beam hitting still water and then reflecting over the natural backstops and specular reflection extending the LSDZ to a circle with a radius equal to NOHD minus the laser to target distance. Of special concern, are aircrews flying in the area without eye protection. These are illustrated in Figures 19, 20 and 21.
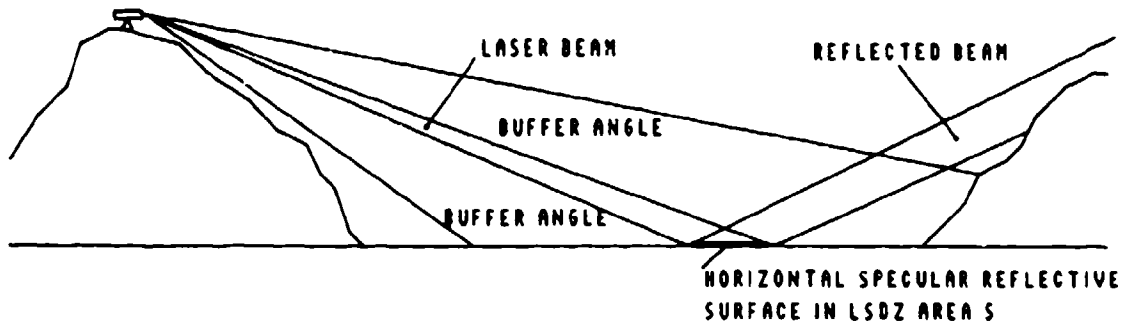
FIGURE 19. LSDZ WITH SPECULAR REFLECTIONS FROM STANDING STILL WATER
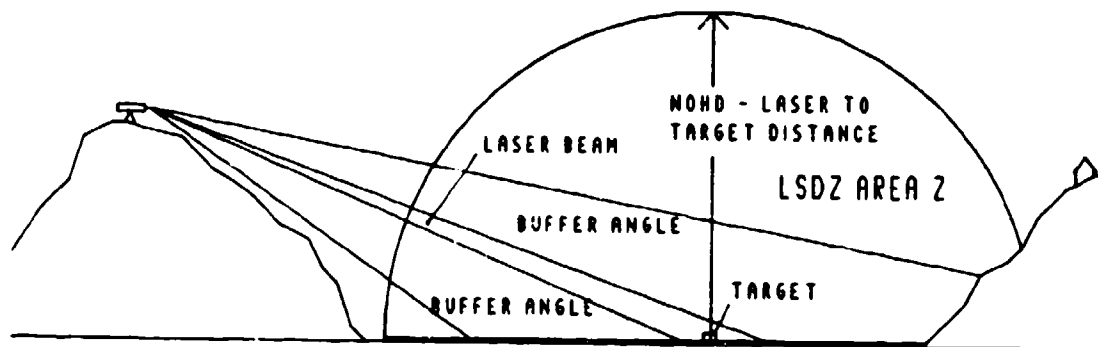
FIGURE 20. LSDZ WITH SPECULAR REFLECTIVE TARGET - SIDE VIEW

18
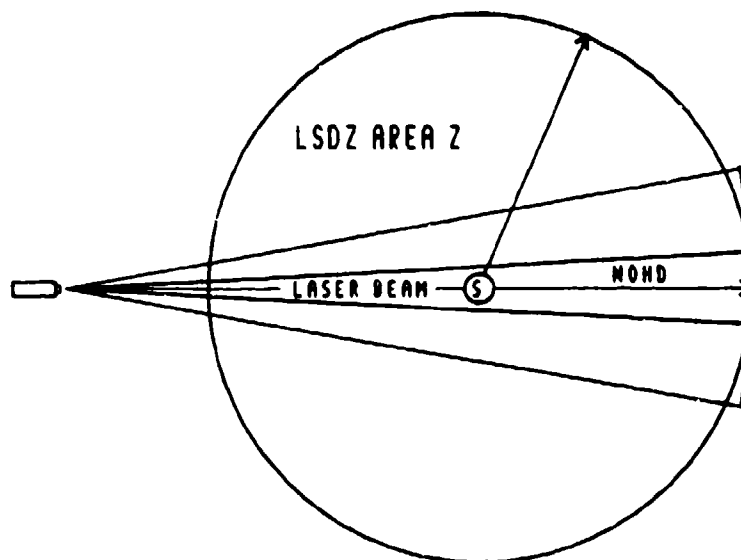
FIGURE 21. LSDZ WITH SPECULAR REFLECTIVE TARGET - TOP VIEW

   c. Siting lasers and targets: As you can see from comparing Figures 9 and 10 and also 17 and 18, site selection for the lasing position and target location can be critical. If you have a choice of target location, first determine the width of the vertical and horizontal buffer zones. Then place the target that distance from the edges of the range boundaries or natural backstops. This procedure will maximize the use of natural backstops and range boundaries.

   d. Atmospheric attenuation: Most lasers used by ground forces have had the NOHD established by measurement and therefore include atmospheric attenuation. If not, the procedure listed in AFOSH Standard 161-10 can be used to convert the calculated NOHD in a vacuum to the NOHD which includes atmospheric attenuation. To estimate atmospheric attenuation for 1064 nanometer lasers, a table in Appendix G provides approximate correction values. Lasers at other wavelengths require separate evaluations.

 3. <u>Other Considerations:</u>

   a. Moving targets or lasers: A moving target or laser will affect the size of the laser surface danger zone and may indicate that the single pulse NOHD is more applicable than the multiple pulse NOHD when evaluating specular reflections. This must be decided on a case by case basis. A common application of this includes evaluating reflection hazards when the angle of lasing is rapidly changing, and therefore the probability of a multiple pulse exposure is small.

   b. Operating outside of controlled area: Targets should never be positioned outside the controlled area (including airspace). Airborne lasers

should not be operated outside the controlled airspace if the potential for the beam striking an object outside the controlled area exists. If this risk is minimal, consider permitting lasing from uncontrolled areas under controlled conditions. Ensure the regional Flight Service Center for the Federal Aviation Administration (FAA) is notified prior to starting this operation so they can publish a Notice to Airmen (NOTAM). The FAA regulation governing this is 7930 2B, Notices to Airmen (NOTAM). Ground laser systems should never be operated outside the controlled area.

IV. RANGE CONTROL PROCEDURES AND RECOMMENDATIONS

A. **Objective:** The underlying concept of laser range safety is to prevent exposure of unprotected personnel from laser radiation in excess of the MPE. This is accomplished by determining where the laser radiation is expected to be, restricting access of unprotected personnel, and removing reflective surfaces from this area.

B. **Target areas:** Recommended target areas are those without specular (mirror-like) surfaces. Glossy foliage, raindrops, snow, and other natural objects are not considered to be specular surfaces that would create ocular hazards.

C. **Sanitized ranges:** If target areas have no flat specular surfaces, then range control measures can be limited to the control of the area where the laser beam hits directly.

D. **Lasing:** Laser devices should only be directed at targets.

E. **Unprotected personnel:** Unprotected personnel must not be exposed to laser radiation greater than the MPE.

F. **Signs:** Local procedures should provide for the placement of laser warning signs at the boundaries of the controlled areas and the access points. This is normally a coordinated process between BES, Ground Safety and the range officer. These signs should be constructed IAW MIL STD 1425. If the hazard zone is within a designated weapons and gunnery range, access controls will be established.

G. **Eye Wear:** Personnel within the LSDZ should wear laser protective eye wear. Eye wear must be approved for the wavelength of the laser system being used and must provide sufficient protection (OD). If more than one type of laser is used, protective eye wear must provide adequate protection for all wavelengths involved (OD greater or equal to the largest minimum OD required for each wavelength).

H. **Optical devices:** Magnifying daylight optical devices, without attenuation, may be used to view the target if flat specular surfaces have been removed from the target area. Specular surfaces can be viewed only if appropriate laser safety filters are placed in the optical train of the magnifying optics. Procedures for calculating the required OD are found in AFOSH Standard 161-10.

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I. **Water and ice:** Still water and smooth ice can reflect laser beams, especially at low angles of incidence. Consider these potential reflections when establishing target areas. Snow is not a specular reflector.

J. **Communications:** The Range Control Officer should have positive control over all lasing operations. Direct communication with the laser operator should be maintained at all times.

V. RANGE LASER SAFETY PROGRAM

A. **AFR 50-46:** Air Force weapon ranges are operated IAW AFR 50-46. If lasing is to be authorized on a weapon range, then the guidelines in AFOSH Standard 161-10 apply. On ranges outside CONUS, specific host-user requirements must also be considered when evaluating the range. Each operating agency is required to publish a supplement to AFR 50-46 covering authorized missions and range control procedures. For lasing operations the specific authorized mission profiles, aircrew and ground laser operator training requirements, range personnel laser training requirements, medical requirements and laser range control procedures should be included in the supplement. The following list contains range control procedures that should be contained in the lasing operations supplement.

1. The size of the designated controlled area or LSDZ will be determined by an evaluation as described above. This evaluation considers the laser emission characteristics; aiming accuracy of the laser; extent of the hazards from direct, diffuse, or specular reflections; danger from exploding targets; possibility of system malfunction; potential for human error; and the topography of the target area.

2. Laser ranges or target areas will be controlled to ensure that personnel are not exposed above the MPE. Methods of controlling the target areas include warning signs at boundaries and access points, observers at strategic locations, fences, etc.

3. If possible, terminate the laser beam by a natural or man-made backstop of nonreflecting materials. This can be accomplished by making use of the terrain contour in the mission profile, and choice of target location.

4. Remove, paint, or cover specularly reflective surfaces within the LSDZ. For ground-to-ground lasing, only the LSDZ area S and backstops need to be cleared.

5. During periodic maintenance of the weapon range, the laser target area will be policed for specular reflectors.

6. All nonessential and unprotected personnel will be excluded from the LSDZ.

7. The control of airspace will be coordinated with the appropriate agency for all ground-to-ground, ground-to-air, air-to-ground, or air-to-air Class 3 or 4 laser beams transmitted through the atmosphere. See Section III.E.3.b for procedures to contact the FAA.

8. Communication with personnel in controlled areas must be maintained during laser operations.

9. Lasing of nontarget vehicles or aircraft is prohibited.

10. Personnel protection equipment commensurate with the hazard, will be provided to all personnel who must be in the hazard zone. When using magnifying devices, a greater hazard should be taken into account because more light is collected by these devices than the naked eye.

11. For maintenance and test operations involving laser designators, the beam will be oriented away from populated areas and will be terminated by a backstop.

B. **Laser Safety Training:** Laser safety training is the responsibility of the Range Safety Officer/NCO and the support Environmental Health Officer. The assigned flight surgeon and BES may also be involved in some medical aspects of this training. Specific responsibilities should be assigned according to the training/experience of assigned personnel. Initial and annual training sessions should be conducted and entered on the individual's training records (AF Form 991). Adequacy of training should be documented in the applicable shop folder. A Navy training video tape is available (Navy tape No. 800909DN, Aircrew Laser Eye Protection) through the base audio visual library.

C. **Eye examinations:** All personnel whose assigned duties are in a laser hazard zone are required to have a laser eye exam prior to and at termination of laser assigned duties. Laser eye exams are to be conducted as prescribed by AFOSH Standard 161-10. For aircrews, this requirement is met by flight physicals.

D. **Eye Wear:** All personnel entering controlled areas during lasing operations must wear the correct laser protective eye wear. Present AF policy requires aircrews to wear laser eye protection during training missions under the following conditions:

1. Exercise mission involving multiship formations.

2. Target areas not cleared of specular reflective surfaces.

3. Ground-based lasers used against aircraft.

E. **Involved agencies:** Normally, a coordinated effort between the range operating agency, BES, and the Base Safety Office is necessary to evaluate the potential hazard of laser systems operated on the range. These agencies and the Environmental Health Officer can develop an appropriate training package for range personnel.

APPENDIX A

HAZARD EVALUATIONS FOR AIRBORNE LASERS

Table A.1. AIR TO GROUND LASER TARGET DESIGNATORS

Summary of Air to Ground Laser Target Designators

Device	Wavelength (nm)	ANSI Class	NOHD-S (m)	NOHD (m)	NOHD-O (m)	OD	OD*	Buffer Angle (mrad)	Beam Divergence (mrad)
Air Force Systems:									
PAVE SPIKE (AN/ASQ-153)	1064	4	5800	10000		4.0		2.5	.35
PAVE TACK (AN/AVQ-26)	1064	4	8200	16000		4.04		2	0**
PAVE KNIFE (AN/ALQ-10)	1064	4	3100	5600		3.7		5	
PAVE SPECTRE (AN/AVQ-19)	1064	4	5000	8900		3.7		5	.33
LANTIRN POD (operational)	1064	4	7500	14800		3.8		2	0**
(Training)	1540	3b	0	0		0		NA	0**
Other Services:									
A6-E TRAM (AN/AAS-33A)	1064	4	9000	14600	58000	4.6	5.8	5	
AN/AAS-37 (OV-10)	1064	4		11200	56200	5.2	5.8	5	
TADS (AAH)	1064	4		20000	70000+	+	5.5+	5	
LAAT (AH-1S)	1064	4		5000	30000	3.4	4.8	5	

KEY:

NOHD - multiple pulse NOHD (also referred to as NOHD-M)
NOHD-S - single pulse NOHD
NOHD-O - NOHD with optical instruments
OD* - OD required in optics of viewing device (assuming 80 mm aperature)
** - Actual divergence classified, use 0 with the specified buffer angle.
+ - Pending evaluation of the production model.

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APPENDIX B

HAZARD EVALUATIONS FOR GROUND BASED LASERS

Table B.1. NOMINAL OCULAR HAZARD DISTANCES AND RANGE SAFETY INFORMATION
FOR FIELDED MILITARY GROUND BASED LASER SYSTEMS

Device	System	ANSI Class	Distances (m) NOHD	NOHD-O	t	s	Buffer Angle (mrad) Static	Moving
********** TANK MOUNTED **********								
AN/VVG-1	M551A1	4	10,000	80,000	10	60	2	Not Permitted
AN/VVS-1	M60A2	4	10,000	80,000	10	100	5	10
AN/VVG-2	M60A3	4	10,000	80,000	10	60	2	5
red "filter" (29 dB)			300	3,100	0	Target	2	5
green "filter" (55 dB)			0	0	0	0	NA	NA
AN/VVG-3	M1	4	7,000	35,000	0	60	2	5
********** MAN PORTABLE **********								
AN/GVT-1	SLT	1	0	0	0	0	NA	NA
AN/GVS-5		4	2,700	20,600	0	200	10 hand-held	
red filter (19 dB)			290	1,800	0	200	10 hand-held	
yellow filter (29 dB)			56	550	0	200	10 hand-held	
AN/PAQ-1	LTD	4	7,700	33,000	0	200	10 hand-held	
AN/TVQ-2 LRF mode	G/VLLD	4	8,000	40,000	0	60	2 on tripod	Not used
yellow filter (8.5 dB)			2,500+	23,000+	0	100+	5 on vehicle	--on the
AN/TVQ-2 LD mode	G/VLLD	4	25,000	80,000	0	60	2 on tripod	move in
						100+	5 on vehicle	training
AN/PAQ-3 LRF mode	MULE	4	6,500	35,000	0	60	2 on tripod	
						200	10 handheld	
AN/PAQ-3 LD mode	MULE	4	20,000	79,000	0	60	2 on tripod	
						200	10 handheld	

KEY;

+ - Pending evaluation of the production model
NOHD - multiple pulse NOHD (also referred to as NOHD-M)
NOHD-O - NOHD with optical instruments
t - diffuse reflection hazard distance
s - a predetermined (by the using service) distance around the target which must be cleared of specular
    reflective surfaces.

Table B.2. EYE PROTECTION REQUIREMENTS FOR FIELDED MILITARY GROUND BASED LASER SYSTEMS

Device	System	Wavelength (nm)	Built-In Safety Filter (OD)	Required Eye Protection (OD) Unaided	Required Eye Protection (OD) Total
			********** TANK MOUNTED **********		
AN/VVG-1	M551A1	694.3	clip-on > 5	5.8	5.8
AN/VVS-1	M60A2	694.3	clip-on > 5	5.8	5.8
AN/VVG-2	M60A3	694.3	clip-on > 5	5.8	5.8
AN/VVG-3	M1	1,064	> 5	4.7	4.7
			********** MAN PORTABLE **********		
AN/GVT-1	SLT	1,064	NA	0	0
AN/GVS-5		1,064	5	3.7	4.4
AN/PAQ-1	LTD	1,064	4	4.2	5.8
AN/TVQ-2	G/VLLD	1,064	YES	3.8	5.5
AN/PAQ-3	MULE	1,064	> 5	3.9	5.8

APPENDIX C

DESCRIPTION OF FIELDED LASER SYSTEMS

DESCRIPTION OF FIELDED LASER SYSTEMS

The following brief description of laser devices is provided for your information.

1. AN/VVS-1 Laser Range Finder mounted on the M60A2 tank.

2. AN/VVG-1 Laser Range Finder mounted on the M551A1 Sheridan vehicle.

3. AN/VVG-2 Laser Range Finder mounted on the M60A3 tank. Used with two filters, the green Eye Safe Simulated Laser Range Finder (ESSLR) filter and the red ESSLR filter. The green ESSLR is eye safe, the red ESSLR is less hazardous than the system without filters (see Appendix B).

4. AN/GVS-5 Laser Range Finder Infrared Observation Set (Handheld).

5. AN/PAQ-1 (LTD) Laser Target Designator. This is a lightweight, handheld, battery operated laser device. Forward observers use it to designate targets.

6. AN/TVQ-2 (G/VLLD) Ground/Vehicle Laser Locator Designator. This is a principle ranging and laser designating device used by Army artillery forward observers with laser energy homing munitions. It is capable of designating stationary or moving vehicular targets and may be used in a stationary, vehicle mounted, or tripod supported dismounted mode. The primary vehicle mount is the Fire Support Team Vehicle (FISTV).

7. AN/PAQ-3 (MULE) Modular Universal Laser Equipment. This is a Marine Corps laser designator used with laser energy homing munitions. The MULE is man portable and is used only in a dismounted mode.

8. Laser Augmented Airborne TOW (LAAT) mounted in the AH-1S COBRA Helicopter. The LAAT system consists of a laser range finder and reciever that is incorporated into the M65 tube launched optically tracked wire guided (TOW) telescopic sight unit.

9. Target Acquisition and Designation System with Pilot Night Vision Sight (TADS/PNVS) mounted in the Apache Advanced Attack Helicopter.

10. AN/AAS-37, Laser Range Finder Designator mounted on the Marine Corps OV-10 Observation Aircraft.

11. M55, Laser Tank Gunnery Trainer

12. Air to Ground Engagement System/Air Defense (AGES/AD) is an extension of MILES to air defense simulation.

13. AN/AAS-33A, Target Recognition Attack Multisensor (TRAM) laser system. This system is mounted on the A6-E Aircraft and has a laser target designator and forward looking infrared (FLIR).

14. Multiple Integrated Laser Engagement System (MILES). The MILES system uses low risk lasers and does not require service members to wear protective eyewear during the conduct of training with the MILES system.

15. LANTIRN System, Low Altitude Navigation and Targeting Infrared System for Night. A two pod system containing a terrain following radar (TFR), forward looking infrared (FLIR), laser designation, and later, a target recognition system. This system is designed to be flown on the F-15, F-16 and A-10. The laser operates at 1064 nm and may have a training modification to operate at 1540 nm which will be eye safe.

16. TASO (Training Aid Support Office) Rifle Marksmanship-Weaponeer-Remedial Rifle Marksmanship Trainer.

17. SHILLELAGH Conduct of Fire Trainer (SCOFT).

18. PAVE PENNY (AN/AAS-35): Laser tracker pod used on the A-10 and A-7 aircraft. Does not contain a laser.

19. PAVE SPECTRE (AN/AVQ-19): Laser tracking and designator used on C-130 gunships.

20. PAVE SPIKE (AN/AVQ-12): Laser tracking and designator pod fitted on F-4 and F-111 aircraft.

21. PAVE TACK (AN/AVQ-26): Advanced optronics pod containing stabilized turret with FLIR, laser designator and tracker used on the F-4, RF-4, and F-111F aircraft.

The following systems are not in the active inventory but are included for background:

22. PAVE ARROW (AN/AVQ-14): This was a laser tracker pod developed for use in conjunction with the PAVE SPOT laser designator used on O-2A FAC spotter planes, C-123, and was planned for use on the F-100. It was eventually merged with the PAVE SWORD program.

23. PAVE BLIND BAT: The PAVE BLIND BAT consisted of a laser target designator to illuminate targets for the PAVE WAY guided bombs. It had an effective range of 18,000 ft and was developed in part for use by AC-130 gunships to aid supporting fighter aircraft.

24. PAVE FIRE: Development of laser scanner in 1969-70 to aid F-4 Phantoms in securing proper target bearing.

25. PAVE GAT: Development of a laser range finder for use on the B-57G.

26. PAVE KNIFE (AN/ALQ-10): The original laser designator pod developed by Aeronutronic-Ford and used in combat in Vietnam 1971-73.

27. PAVE LANCE: Developmental effort to replace the PAVE KNIFE by improving night capability with the addition of a forward looking infrared (FLIR) in place of the low light television (LLTV). Superseded by PAVE TACK.

28. PAVE LICHT (AN/AVQ-9): Stablizer laser designator developed for the F-4 Phantom.

29. PAVE MACK: Development of laser seeker head for air to ground rockets. Project was also called LARS (Laser Aided Rocket System) and rockets were to be used in conjunction with FAC (Forward Air Controller) mounted PAVE SPOT designator.

30. PAVE NAIL (AN/AVQ-13): Modification of 18 OV-10 FAC aircraft with stabilized periscopic night sight and laser designator. Program coordinated with PAVE PHANTOM and PAVE SPOT.

31. PAVE PHANTOM: Addition of an ARN-92 Loran and computer to the F-4D allowing aircraft to store targeting information for eight separate positions illuminated by OV-10 PAVE NAIL.

32. PAVE POINTER: Palletized gun direction system consisting of a laser designator/range finder and low light TV employed on a C-123 and forerunner of subsequent gunship fire control systems.

33. PAVE PRISM: Aerodyne Research effort to develop IR and active laser seekers for use on the ASRAAM air-to-air missile.

34. PAVE PRONTO: Modification of AC-130 gunships for night attack including an LTV Electro systems night observation camera, AAD-4 or AAD-6 FLIR and AVQ-17 illuminator.

35. PAVE SCOPE: Target acquisition aids for jet fighter aircraft such as the Eagle Eye (LAD) AN/AVG-8, and TISEO.

36. PAVE SHIELD: Classified project undertaken by Aeronautical Research Associates.

37. PAVE SPOT (AN/AVQ-12): Stabilized periscopic night vision sight developed by Varo for use on the O-2A FAC. The system was fitted with a Korad laser designator (Nd: YAG) and first went into service in 1970 over Vietnam.

38. PAVE STRIKE: A related group of air-to-ground strike programs including PAVE TACK and IR guided bombs.

39. PAVE SWORD (AN/AVQ-11): Laser tracker designed to pick up energy from targets illuminated by O-2A spotter planes. Used on F-4, and bore sighted with its radar set.

40. PAVE WAY: Code name for a wide variety of guided bomb projects, also refers to AN/AVQ-9 laser designator developed by Martin Marietta in the late 1960s for use on the F-4 Phantom.

APPENDIX D

FOOTPRINT TABLES FOR COMMON AIRBORNE SYSTEMS

Table D.1
LASER FOOTPRINT TABLE for: PAVE SPIKE (USING VACUUM NOHD)

Table based on: Flat terrain, Buffer= 2.5 mrad, Divergence= .35 mrad
NOHD= 10000 meters (32800 feet or 5.4 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

SLANT RANGE (nautical miles, feet, and meters)

ALTITUDE (feet)	FOOTPRINT		1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	ft	1180	5850	14600	8500	2420	0	0	0	0
		m	359	1780	4440	2590	737	0	0	0	0
	AFT	ft	850	2980	5970	9580	13600	18000	22600	27500	32500
		m	259	909	1820	2920	4150	5490	6900	8380	9900
200	FORWARD	ft	537	2360	5880	8590	2420	0	0	0	0
		m	164	719	1790	2590	737	0	0	0	0
	AFT	ft	457	1700	3570	5960	8780	11900	15400	19200	23100
		m	139	518	1090	1820	2680	3640	4700	5840	7040
300	FORWARD	ft	348	1460	3540	6720	2420	0	0	0	0
		m	106	450	1080	2050	737	0	0	0	0
	AFT	ft	312	1190	2550	4330	6480	8940	11700	0	0
		m	95	362	777	1320	1970	2730	3560	0	0
400	FORWARD	ft	257	1070	2530	4720	2420	0	0	0	0
		m	78	328	771	1440	737	0	0	0	0
	AFT	ft	237	913	1980	3400	5130	7150	0	0	0
		m	72	278	604	1040	1560	2180	0	0	0
500	FORWARD	ft	204	845	1970	3630	2420	0	0	0	0
		m	62	258	600	1110	738	0	0	0	0
	AFT	ft	191	742	1620	2800	4250	5950	0	0	0
		m	58	226	494	852	1290	1810	0	0	0
600	FORWARD	ft	169	696	1610	2950	2420	0	0	0	0
		m	52	212	491	900	738	0	0	0	0
	AFT	ft	160	625	1370	2380	3620	5100	0	0	0
		m	49	190	418	724	1100	1550	0	0	0
700	FORWARD	ft	144	592	1360	2490	2420	0	0	0	0
		m	44	180	416	758	738	0	0	0	0
	AFT	ft	138	539	1190	2070	3160	4460	0	0	0
		m	42	164	362	630	963	1360	0	0	0
800	FORWARD	ft	126	515	1180	2150	2420	0	0	0	0
		m	38	157	361	655	738	0	0	0	0
	AFT	ft	121	475	1050	1830	2800	3960	0	0	0
		m	37	145	319	557	854	1210	0	0	0
	WIDTH	ft	33	65	98	130	163	195	228	260	293
		m	10	20	30	40	50	59	69	79	89

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

Table D.2
LASER FOOTPRINT TABLE for: PAVE SPIKE (INCLUDING ATMOSPHERIC ATTENUATION FOR LASING FROM ALTITUDES BELOW 1 km MSL ONLY)

Table based on: Flat terrain, Buffer= 2.5 mrad, Divergence= .35 mrad
MOMO= 8200 meters (26896 feet or 4.4 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

SLANT RANGE (nautical miles, feet, and meters)

ALTITUDE (feet)	FOOTPRINT	1.0 NM	2.0 NM	3.0 NM	4.0 NM	5.0 NM	6.0 NM	7.0 NM	8.0 NM	9.0 NM
100	FORWARD	1180 ft / 359 m	5850 ft / 1780 m	8670 ft / 2640 m	2590 ft / 790 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	850 ft / 259 m	2980 ft / 909 m	5970 ft / 1820 m	9580 ft / 2920 m	13600 ft / 4150 m	18000 ft / 5490 m	22600 ft / 6900 m	27500 ft / 8380 m	32500 ft / 9900 m
200	FORWARD	537 ft / 164 m	2360 ft / 719 m	5880 ft / 1790 m	2590 ft / 790 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	457 ft / 139 m	1700 ft / 518 m	3570 ft / 1090 m	5960 ft / 1820 m	8780 ft / 2680 m	11900 ft / 3640 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
300	FORWARD	348 ft / 106 m	1480 ft / 450 m	3540 ft / 1080 m	2590 ft / 790 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	312 ft / 95 m	1190 ft / 362 m	2550 ft / 777 m	4330 ft / 1320 m	6480 ft / 1970 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
400	FORWARD	257 ft / 78 m	1070 ft / 328 m	2530 ft / 771 m	2590 ft / 790 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	237 ft / 72 m	913 ft / 278 m	1980 ft / 604 m	3400 ft / 1040 m	5130 ft / 1560 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
500	FORWARD	204 ft / 62 m	845 ft / 258 m	1970 ft / 600 m	2590 ft / 790 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	191 ft / 58 m	742 ft / 226 m	1620 ft / 494 m	2800 ft / 852 m	4250 ft / 1290 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
600	FORWARD	169 ft / 52 m	696 ft / 212 m	1610 ft / 491 m	2590 ft / 790 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	160 ft / 49 m	625 ft / 190 m	1370 ft / 418 m	2360 ft / 724 m	3620 ft / 1100 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
700	FORWARD	144 ft / 44 m	592 ft / 180 m	1360 ft / 416 m	2490 ft / 758 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	138 ft / 42 m	539 ft / 164 m	1190 ft / 362 m	2070 ft / 630 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
800	FORWARD	126 ft / 38 m	515 ft / 157 m	1180 ft / 361 m	2150 ft / 655 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	121 ft / 37 m	475 ft / 145 m	1050 ft / 319 m	1830 ft / 557 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	WIDTH	33 ft / 10 m	65 ft / 20 m	98 ft / 30 m	130 ft / 40 m	163 ft / 50 m	195 ft / 59 m	228 ft / 69 m	260 ft / 79 m	293 ft / 89 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

Table D.3
LASER FOOTPRINT TABLE for: PAVE TACK (USING VACUUM WOMD)

Table based on: Flat terrain, Buffer= 2 mrad, Divergence= 0 mrad
WOMD- 16000 meters (52480 feet or 8.6 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

SLANT RANGE (nautical miles, feet, and meters)

ALTITUDE (feet)	FOOTPRINT	1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	841 ft / 256 m	3930 ft / 1190 m	10500 ft / 3190 m	23000 ft / 7010 m	22100 ft / 6740 m	16000 ft / 4880 m	9950 ft / 3030 m	3870 ft / 1180 m	0 ft / 0 m
	AFT	658 ft / 201 m	2380 ft / 724 m	4870 ft / 1480 m	7950 ft / 2420 m	11500 ft / 3500 m	15400 ft / 4690 m	19600 ft / 5960 m	24000 ft / 7300 m	28600 ft / 8710 m
200	FORWARD	393 ft / 120 m	1680 ft / 512 m	4060 ft / 1240 m	7800 ft / 2380 m	13300 ft / 4040 m	16000 ft / 4880 m	9950 ft / 3030 m	3870 ft / 1180 m	0 ft / 0 m
	AFT	348 ft / 106 m	1320 ft / 401 m	2810 ft / 857 m	4750 ft / 1450 m	7080 ft / 2160 m	9740 ft / 2970 m	12700 ft / 3870 m	15900 ft / 4850 m	19300 ft / 5890 m
300	FORWARD	257 ft / 78 m	1070 ft / 327 m	2520 ft / 769 m	4700 ft / 1430 m	7720 ft / 2350 m	11700 ft / 3570 m	9950 ft / 3030 m	3870 ft / 1180 m	0 ft / 0 m
	AFT	237 ft / 72 m	911 ft / 278 m	1980 ft / 602 m	3390 ft / 1030 m	5120 ft / 1560 m	7130 ft / 2170 m	9400 ft / 2860 m	11900 ft / 3630 m	14600 ft / 4450 m
400	FORWARD	190 ft / 58 m	786 ft / 240 m	1830 ft / 557 m	3360 ft / 1020 m	5440 ft / 1660 m	8130 ft / 2480 m	9950 ft / 3030 m	3870 ft / 1180 m	0 ft / 0 m
	AFT	179 ft / 55 m	696 ft / 212 m	1520 ft / 464 m	2630 ft / 803 m	4010 ft / 1220 m	5620 ft / 1710 m	7460 ft / 2270 m	9500 ft / 2900 m	11700 ft / 3580 m
500	FORWARD	151 ft / 46 m	621 ft / 189 m	1430 ft / 437 m	2620 ft / 798 m	4200 ft / 1280 m	6220 ft / 1900 m	8720 ft / 2660 m	3870 ft / 1180 m	0 ft / 0 m
	AFT	144 ft / 44 m	563 ft / 172 m	1240 ft / 378 m	2150 ft / 656 m	3290 ft / 1000 m	4640 ft / 1410 m	6180 ft / 1880 m	7910 ft / 2410 m	9810 ft / 2990 m
600	FORWARD	126 ft / 38 m	513 ft / 156 m	1180 ft / 359 m	2140 ft / 653 m	3420 ft / 1040 m	5040 ft / 1540 m	7030 ft / 2140 m	3870 ft / 1180 m	0 ft / 0 m
	AFT	121 ft / 37 m	473 ft / 144 m	1040 ft / 318 m	1820 ft / 555 m	2790 ft / 852 m	3950 ft / 1200 m	5280 ft / 1610 m	6780 ft / 2070 m	8430 ft / 2570 m
700	FORWARD	107 ft / 33 m	437 ft / 133 m	1000 ft / 305 m	1810 ft / 553 m	2890 ft / 880 m	4240 ft / 1290 m	5880 ft / 1790 m	3870 ft / 1180 m	0 ft / 0 m
	AFT	104 ft / 32 m	408 ft / 124 m	902 ft / 275 m	1580 ft / 481 m	2430 ft / 740 m	3440 ft / 1050 m	4610 ft / 1400 m	5930 ft / 1810 m	7390 ft / 2250 m
800	FORWARD	94 ft / 29 m	381 ft / 116 m	870 ft / 265 m	1570 ft / 479 m	2500 ft / 761 m	3660 ft / 1110 m	5060 ft / 1540 m	3870 ft / 1180 m	0 ft / 0 m
	AFT	91 ft / 28 m	358 ft / 109 m	795 ft / 242 m	1390 ft / 424 m	2140 ft / 654 m	3050 ft / 928 m	4090 ft / 1250 m	5270 ft / 1610 m	6580 ft / 2000 m
	WIDTH	24 ft / 7 m	49 ft / 15 m	73 ft / 22 m	97 ft / 30 m	122 ft / 37 m	146 ft / 44 m	170 ft / 52 m	194 ft / 59 m	219 ft / 67 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

LASER FOOTPRINT TABLE for: PAVE TACK (INCLUDING ATMOSPHERIC ATTENUATION FOR LASING FROM ALTITUDES BELOW 1 km MSL ONLY)

Table based on: Flat terrain, Buffer= 2 mrad, Divergence= 0 mrad
MOMD= 12000 meters (39360 feet or 6.5 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

SLANT RANGE (nautical miles, feet, and meters)

ALTITUDE (feet)	FOOTPRINT	1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	841 ft / 256 m	3900 ft / 1190 m	10500 ft / 3190 m	15100 ft / 4590 m	8980 ft / 2740 m	2900 ft / 885 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	658 ft / 201 m	2380 ft / 724 m	4870 ft / 1480 m	7950 ft / 2420 m	11500 ft / 3500 m	15400 ft / 4690 m	19600 ft / 5960 m	24000 ft / 7300 m	28600 ft / 8710 m
200	FORWARD	393 ft / 120 m	1680 ft / 512 m	4060 ft / 1240 m	7800 ft / 2380 m	8980 ft / 2740 m	2900 ft / 885 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	348 ft / 106 m	1320 ft / 401 m	2810 ft / 857 m	4750 ft / 1450 m	7080 ft / 2160 m	9740 ft / 2970 m	12700 ft / 3870 m	15900 ft / 4850 m	19300 ft / 5890 m
300	FORWARD	257 ft / 78 m	1070 ft / 327 m	2520 ft / 769 m	4700 ft / 1430 m	7720 ft / 2350 m	2900 ft / 885 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	237 ft / 72 m	911 ft / 278 m	1980 ft / 602 m	3390 ft / 1030 m	5120 ft / 1560 m	7130 ft / 2170 m	9400 ft / 2860 m	11900 ft / 3630 m	0 ft / 0 m
400	FORWARD	190 ft / 58 m	786 ft / 240 m	1830 ft / 557 m	3360 ft / 1020 m	5440 ft / 1660 m	2900 ft / 885 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	179 ft / 55 m	696 ft / 212 m	1520 ft / 464 m	2630 ft / 803 m	4010 ft / 1220 m	5620 ft / 1710 m	7460 ft / 2270 m	9500 ft / 2900 m	0 ft / 0 m
500	FORWARD	151 ft / 46 m	621 ft / 189 m	1430 ft / 437 m	2620 ft / 798 m	4200 ft / 1280 m	2900 ft / 885 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	144 ft / 44 m	563 ft / 172 m	1240 ft / 378 m	2150 ft / 656 m	3290 ft / 1000 m	4640 ft / 1410 m	6180 ft / 1880 m	0 ft / 0 m	0 ft / 0 m
600	FORWARD	126 ft / 38 m	513 ft / 156 m	1160 ft / 359 m	2140 ft / 653 m	3420 ft / 1040 m	2900 ft / 885 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	121 ft / 37 m	473 ft / 144 m	1040 ft / 318 m	1820 ft / 555 m	2790 ft / 852 m	3950 ft / 1200 m	5280 ft / 1610 m	0 ft / 0 m	0 ft / 0 m
700	FORWARD	107 ft / 33 m	437 ft / 133 m	1000 ft / 305 m	1810 ft / 553 m	2890 ft / 880 m	2900 ft / 885 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	104 ft / 32 m	408 ft / 124 m	902 ft / 275 m	1580 ft / 481 m	2430 ft / 740 m	3440 ft / 1050 m	4610 ft / 1400 m	0 ft / 0 m	0 ft / 0 m
800	FORWARD	94 ft / 29 m	381 ft / 116 m	870 ft / 265 m	1570 ft / 479 m	2500 ft / 761 m	2900 ft / 885 m	0 ft / 0 m	0 ft / 0 m	0 ft / 0 m
	AFT	91 ft / 28 m	358 ft / 109 m	795 ft / 242 m	1390 ft / 424 m	2140 ft / 654 m	3050 ft / 928 m	4090 ft / 1250 m	0 ft / 0 m	0 ft / 0 m
	WIDTH	24 ft / 7 m	49 ft / 15 m	73 ft / 22 m	97 ft / 30 m	122 ft / 37 m	146 ft / 44 m	170 ft / 52 m	194 ft / 59 m	219 ft / 67 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

Table D.5

LASER FOOTPRINT TABLE for: ANY LASER SYSTEM WITH BEAM DIVERGENCE < 0.5 mrad

Table based on: Flat terrain, Buffer= 5 mrad, Divergence= 0 mrad
MXMD= 100000 meters (328000 feet or 54.0 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

ALTITUDE (feet)	FOOTPRINT	1.0 NM	2.0 NM	3.0 NM	4.0 NM	5.0 NM	6.0 NM	7.0 NM	8.0 NM	9.0 NM
100	FORWARD	2650 ft / 808 m	18800 ft / 5740 m	188000 ft / 57200 m	304000 ft / 92600 m	298000 ft / 90700 m	292000 ft / 88900 m	285000 ft / 87000 m	279000 ft / 85200 m	273000 ft / 83300 m
	AFT	1420 ft / 432 m	4590 ft / 1400 m	8690 ft / 2650 m	13300 ft / 4060 m	18300 ft / 5580 m	23500 ft / 7180 m	28900 ft / 8820 m	34400 ft / 10500 m	40000 ft / 12200 m
200	FORWARD	1090 ft / 332 m	5300 ft / 1620 m	15300 ft / 4650 m	37600 ft / 11500 m	95900 ft / 29200 m	292000 ft / 88900 m	285000 ft / 87000 m	279000 ft / 85200 m	273000 ft / 83300 m
	AFT	801 ft / 244 m	2830 ft / 863 m	5710 ft / 1740 m	9190 ft / 2800 m	13100 ft / 4000 m	17400 ft / 5300 m	21900 ft / 6680 m	26700 ft / 8130 m	31600 ft / 9630 m
300	FORWARD	685 ft / 209 m	3090 ft / 941 m	7950 ft / 2420 m	16500 ft / 5040 m	31200 ft / 9500 m	56500 ft / 17200 m	104000 ft / 31600 m	207000 ft / 63200 m	273000 ft / 83300 m
	AFT	559 ft / 170 m	2050 ft / 624 m	4250 ft / 1290 m	7010 ft / 2140 m	10200 ft / 3110 m	13800 ft / 4200 m	17600 ft / 5380 m	21800 ft / 6630 m	26100 ft / 7950 m
400	FORWARD	499 ft / 152 m	2160 ft / 663 m	5380 ft / 1640 m	10600 ft / 3230 m	18600 ft / 5670 m	30500 ft / 9300 m	48300 ft / 14700 m	75300 ft / 22900 m	118000 ft / 36000 m
	AFT	429 ft / 131 m	1600 ft / 488 m	3380 ft / 1030 m	5650 ft / 1730 m	8360 ft / 2550 m	11400 ft / 3480 m	14800 ft / 4500 m	18400 ft / 5600 m	22200 ft / 6770 m
500	FORWARD	393 ft / 120 m	1680 ft / 512 m	4060 ft / 1240 m	7800 ft / 2380 m	13300 ft / 4040 m	20900 ft / 6380 m	31500 ft / 9530 m	46000 ft / 14000 m	66000 ft / 20100 m
	AFT	348 ft / 106 m	1320 ft / 401 m	2810 ft / 857 m	4750 ft / 1450 m	7080 ft / 2160 m	9740 ft / 2970 m	12700 ft / 3870 m	15900 ft / 4850 m	19300 ft / 5890 m
600	FORWARD	324 ft / 99 m	1370 ft / 417 m	3260 ft / 995 m	6170 ft / 1880 m	10300 ft / 3140 m	15900 ft / 4850 m	23400 ft / 7120 m	33100 ft / 10100 m	45800 ft / 14000 m
	AFT	293 ft / 89 m	1120 ft / 341 m	2400 ft / 733 m	4090 ft / 1250 m	6140 ft / 1870 m	8500 ft / 2590 m	11100 ft / 3390 m	14000 ft / 4270 m	17100 ft / 5220 m
700	FORWARD	276 ft / 84 m	1150 ft / 352 m	2730 ft / 832 m	5110 ft / 1560 m	8420 ft / 2570 m	12800 ft / 3910 m	18600 ft / 5660 m	25900 ft / 7880 m	35100 ft / 10700 m
	AFT	253 ft / 77 m	971 ft / 296 m	2100 ft / 640 m	3600 ft / 1100 m	5420 ft / 1650 m	7530 ft / 2300 m	9910 ft / 3020 m	12500 ft / 3820 m	15400 ft / 4680 m
800	FORWARD	240 ft / 73 m	999 ft / 304 m	2340 ft / 714 m	4350 ft / 1330 m	7120 ft / 2170 m	10800 ft / 3280 m	15400 ft / 4690 m	21200 ft / 6470 m	28400 ft / 8650 m
	AFT	222 ft / 68 m	858 ft / 262 m	1860 ft / 568 m	3210 ft / 977 m	4850 ft / 1480 m	6770 ft / 2060 m	8930 ft / 2720 m	11300 ft / 3450 m	13900 ft / 4250 m
	WIDTH	61 ft / 19 m	122 ft / 37 m	182 ft / 56 m	243 ft / 74 m	304 ft / 93 m	365 ft / 111 m	425 ft / 130 m	486 ft / 149 m	547 ft / 167 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

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APPENDIX E

SAMPLE RANGE EVALUATION A, AIR TO GROUND MODE,
GENERAL CASES, FLAT TERRAIN

SAMPLE RANGE EVALUATION B, AIR TO GROUND MODE,
SPECIFIED APPROACH TRACK, FLAT TERRAIN

SAMPLE RANGE EVALUATION C, AIR TO GROUND MODE,
SPECIFIED FLIGHT PROFILE, COMPLEX TERRAIN

SAMPLE RANGE EVALUATION D, GROUND TO GROUND MODE,
COMPLEX TERRAIN

AIR TO GROUND MODE, GENERAL CASE, FLAT TERRAIN

1. Given: Figure E.1 shows a bombing range with an area labeled target area. The target to be lased is in the center of the target area. It has no reflective surfaces exposed. The larger area outlined is the controlled range area. The range owner wants to allow Air Force and Navy units to lase this target and wants no restrictions on attack angle.
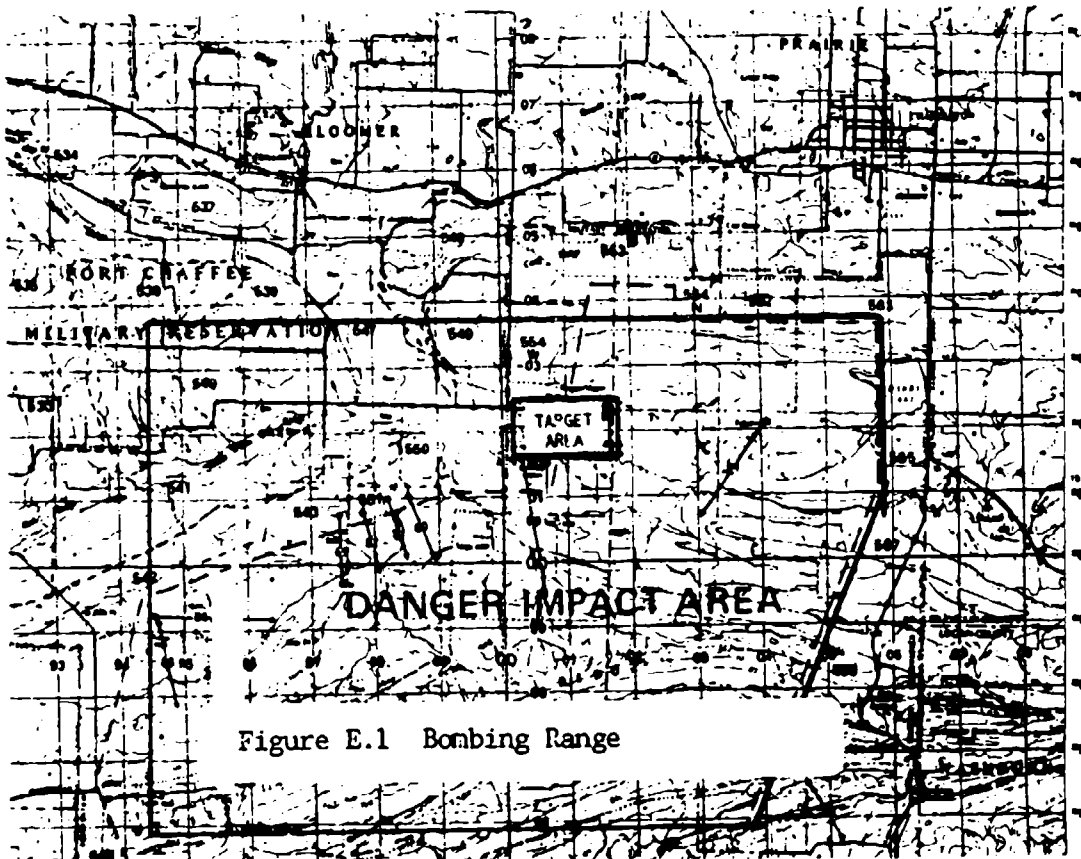
Figure E.1 Bombing Range

2. The first step in evaluating this situation would be to evaluate each laser to be used on the range. If this information is not readily available, or you want to make the evaluation general enough to allow any laser system to be used on the range, a conservative evaluation can be performed. For this evaluation a five milliradian (mrad) buffer zone is used. Since almost any laser target designator will have a divergence of less than 0.5 mrad, the divergence can be ignored.

3. The range and target locations are shown on the map above. Since the size of the range will be the controlling factor, the largest LSDZ will be drawn on the map and the allowable flight profiles determined from its dimensions. Since the attack will be from any direction, the LSDZ will be a circle as shown on Figure E.2.
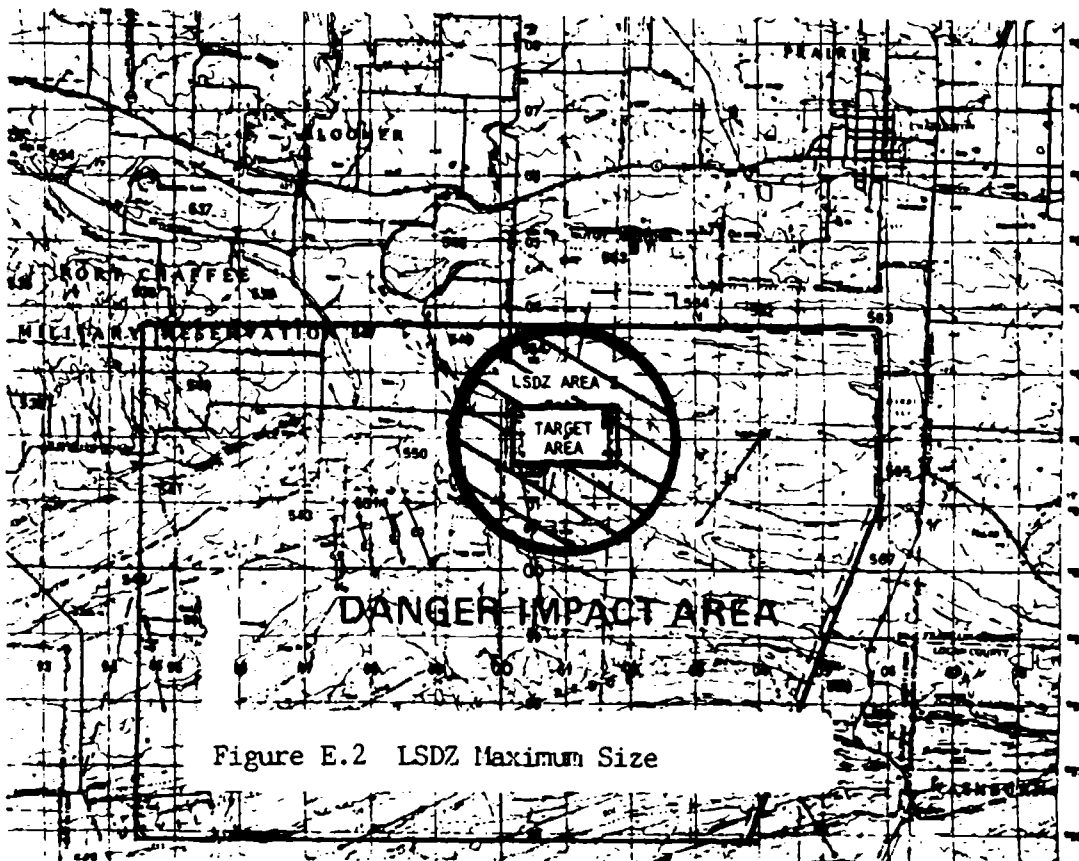
Figure E.2   LSDZ Maximum Size

4.   The grid on this map is 1000 meters. Therefore, the controlling footprint dimension will be approximately 1700 meters (5576 feet). From the footprint Table D.5 in Appendix D, for lasers with a beam divergence less than 0.5 mrad and a 5 mrad buffer angle the following flight restrictions can be found:

Altitude	Maximum Range (km)
100	1
200	2
300	2
400	3
500	3
600	3
700	4
800	4
900	5
1000	5

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5. If these flight restrictions are acceptable to the range operator, then any laser system with a beam divergence less than 0.5 mrad can be used on this range under the flight restrictions listed above. Additionally, the LSDZ area Z outlined on the map above must be cleared of specularly reflective surfaces and unprotected personnel excluded from the area.

6. If these flight restrictions are too severe, the following alternatives are available:

    a. Restrict the approach bearings to make the most use of the available land.

    b. Perform a separate evaluation for each laser system to be used on the range.

    c. Move the target to the center of the range.

    d. Buy more land.

    e. Find another range.

SAMPLE RANGE EVALUATION B

AIR TO GROUND MODE, SPECIFIED APPROACH TRACK, FLAT TERRAIN

1. Given:

   Laser System: PAVE TACK

   Flight Profile:

   > Range: 1-9 km
   > Altitude: 100-500 feet AGL
   > Run-in heading: from west and southwest along the track shown below

   Targets: six separate targets in one area as shown on Figure E.3.

Figure E.3 Target Area and Approach

2. The following information is shown in Appendix A for the PAVE TACK system:

   Wavelength: 1064 nm
   ANSI Class: 4
   Single Pulse NOHD: 8241 m
   Multiple Pulse NOHD: 16000 m
   OD Required: 4.04
   Buffer Angle: 2 mrad
   Beam Divergence: 0 (actual divergence is classified and is contained
                     in the buffer angle)

From this information we see that the laser is not eye safe, eye protection required to view the laser beam directly must have an OD of 4.04 at 1064 nm, the hazard distance excluding atmospheric attenuation is 16,000 meters, the beam divergence is classified, and zero may be used for the divergence when using the 2 milliradian specified buffer angle. For this evaluation, we used the 16,000 meter NOHD, which does not include atmospheric attenuation. Using the NOHD which includes atmospheric attenuation would be more appropriate in actual practice.

3. The range is shown in Figure E.3. Since the ground is fairly flat, extensive modification of the flat terrain determined LSDZ will not be required. Note the proximity of the town of Charleston and small size of the range. These factors will cause the flight profiles to be limited.

4. The target area location is shown on the Figure E.3.

5. To determine the size of the LSDZ and the limits of flight profiles, footprints were drawn on maps to see where the laser beam was expected to hit. This was done at discrete altitudes and ranges along the flight path. Figures E.4 through E.8 represent the footprints as boxes. The lines connected to the boxes show the locations of the aircraft for that footprint. The numbers at the end of the lines indicate the distance to the far edge of the target area in kilometers.

Figure E.4   PAVE TACK - 100' AGL

Figure E.5 PAVE TACK - 200' AGL

Figure E.6 PAVE TACK - 300' AGL

Figure E.7   PAVE TACK - 400' AGL

Figure E.8   PAVE TACK - 500' AGL

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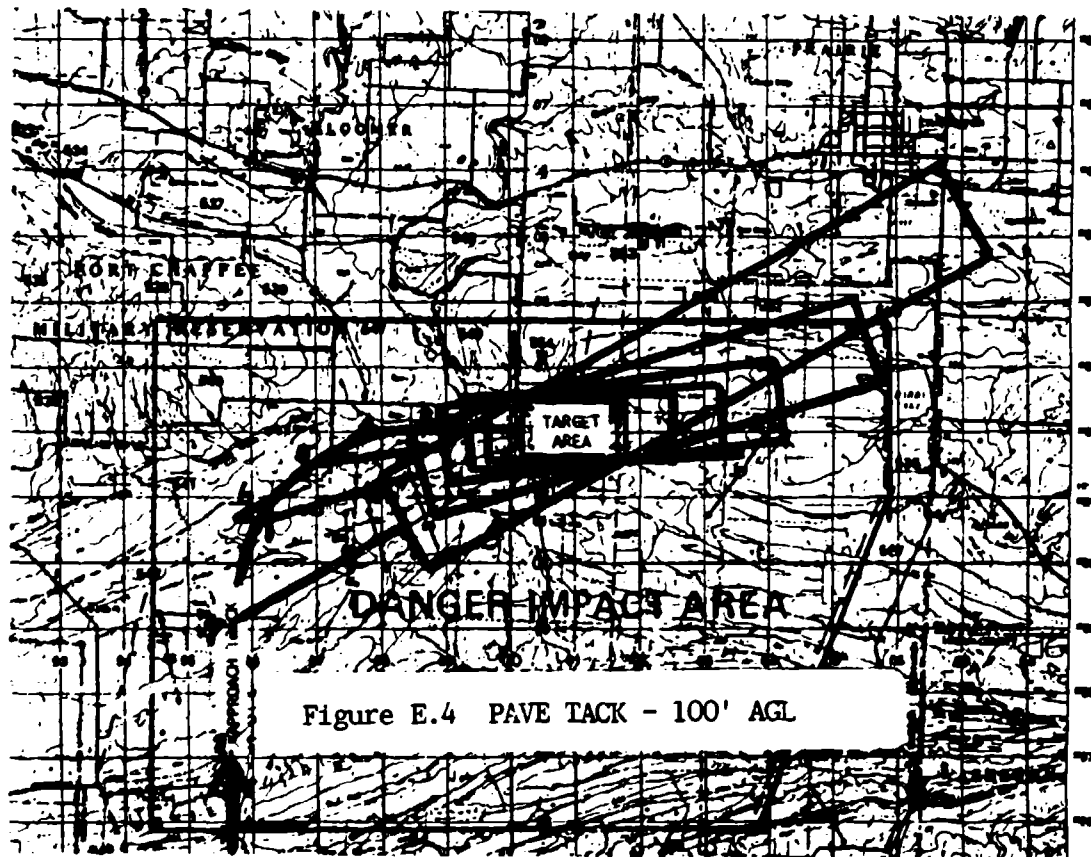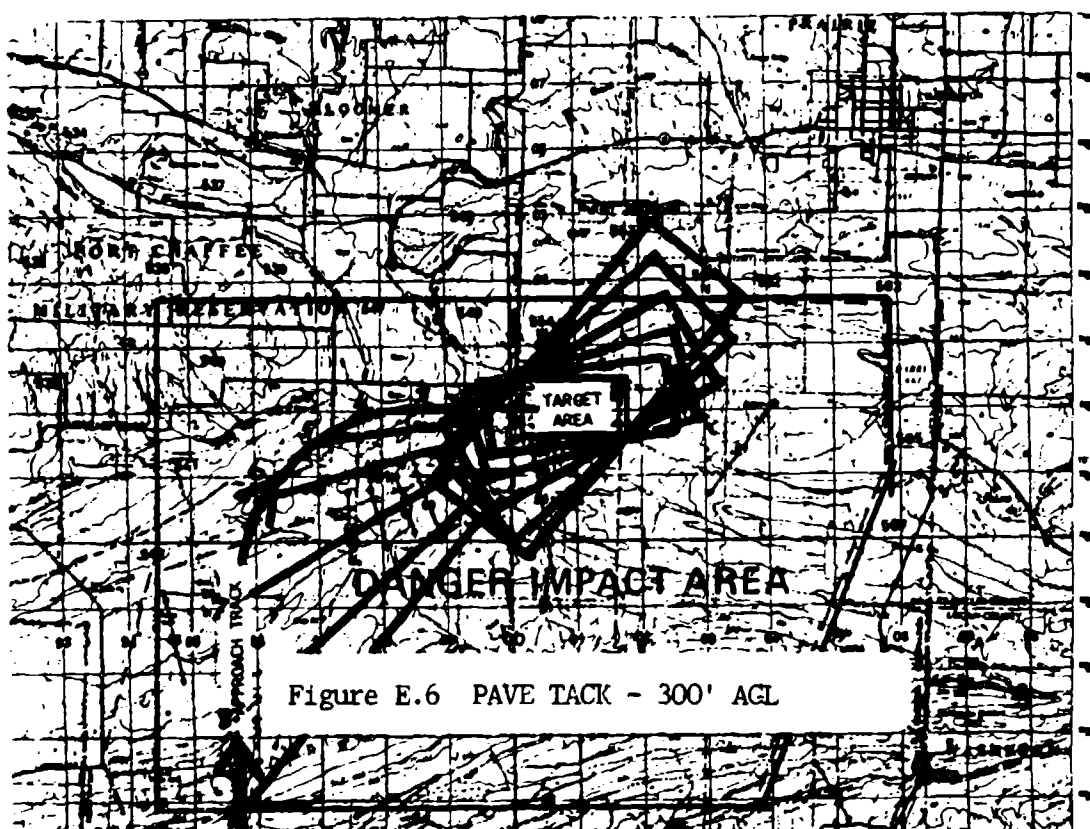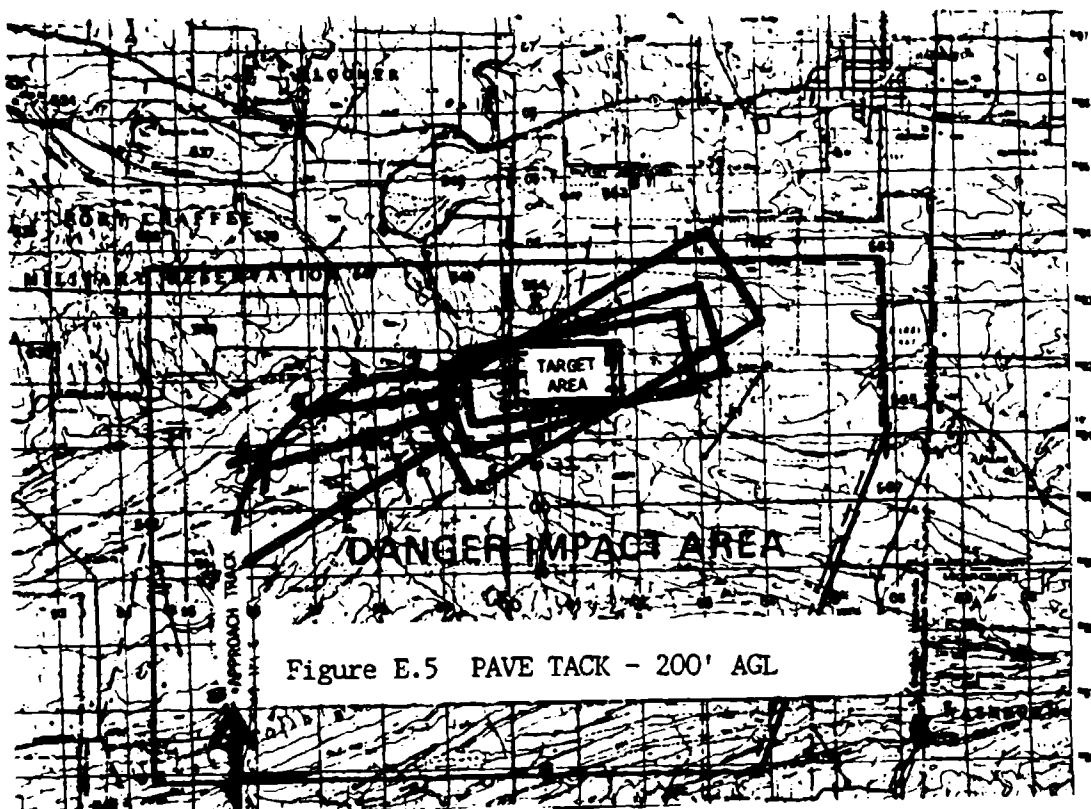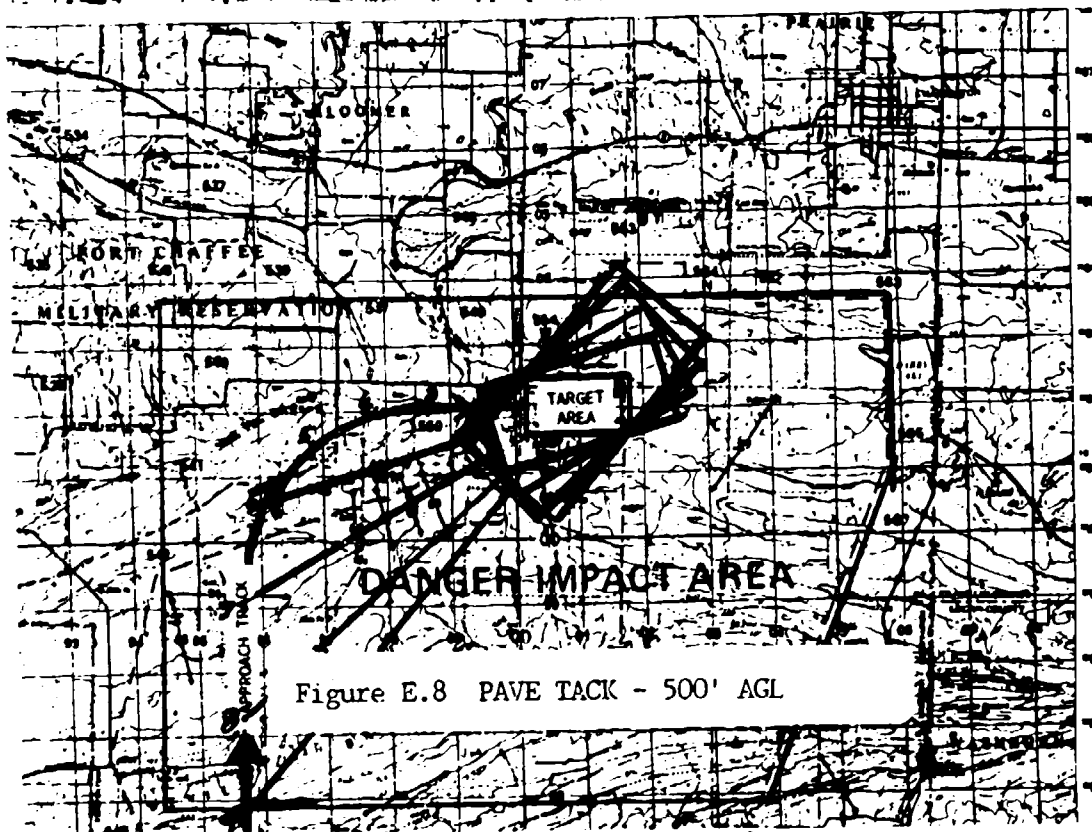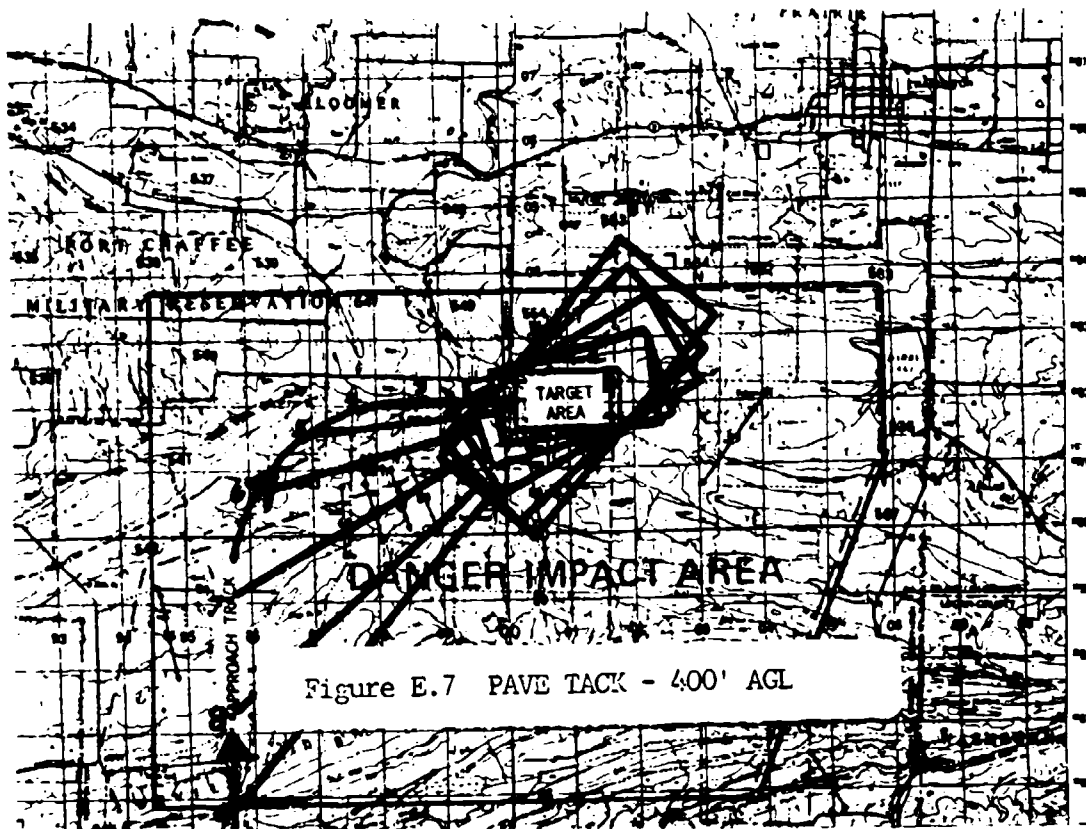
6. As you can see, the further the aircraft is from the target, the larger
the footprint gets. The further south the aircraft is, the more likely the
footprint will not fit within the laser range. The following table summarizes
the maximum lasing distance for each altitude to keep the laser beam within
the laser range. These distances will be the limitations placed on the flight
profiles.

Altitude (AGL in feet)	Max Range (km)
100	5
200	6
300	7
400	7
500	7

7. The LSDZ for the example would be the union of all the footprints found
within the laser range. This area is shown on Figure E.9. This area must be
cleared of all specular surfaces and unprotected personnel excluded.

Figure E.9   PAVE TACK LSDZ

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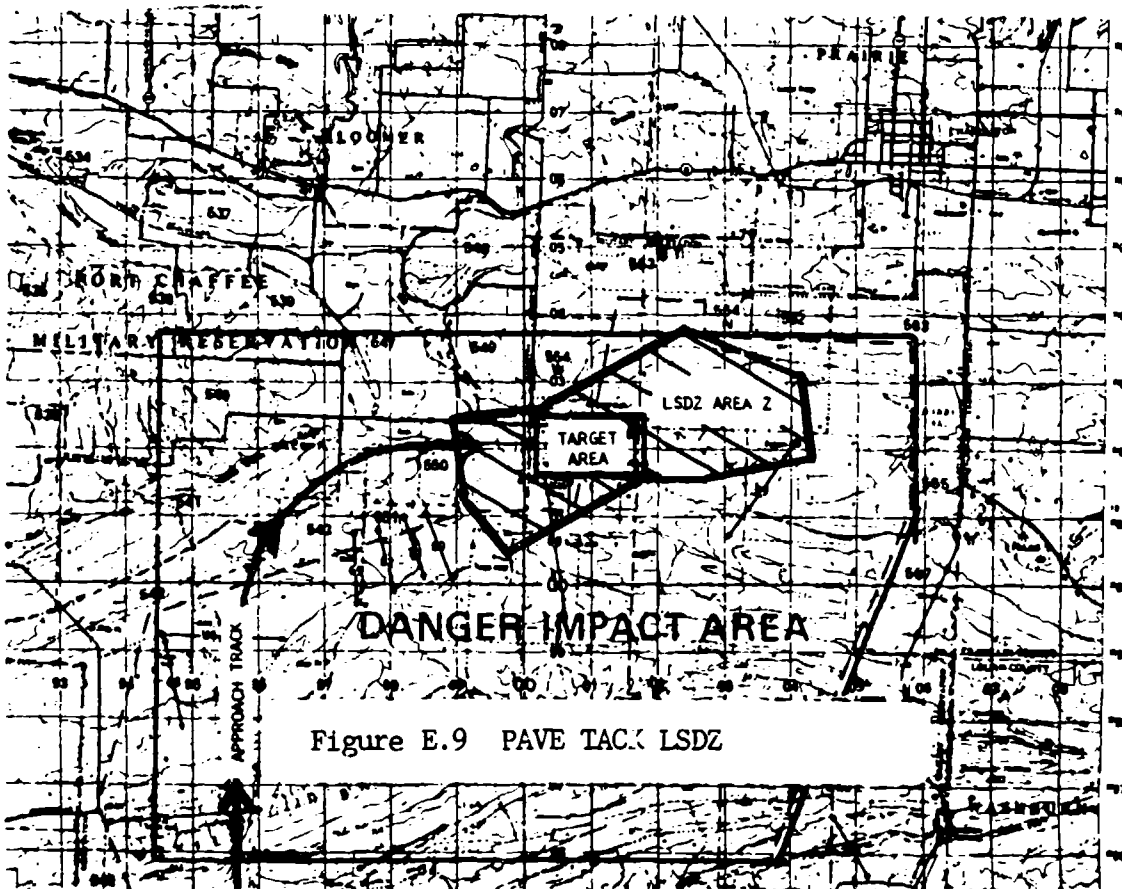
SAMPLE RANGE EVALUATION C

SPECIFIED FIGHT PROFILE, COMPLEX TERRAIN

1. Given:

   Laser System: PAVE SPIKE

   Flight Profiles:

   > Range: 1-4 nautical miles
   > Altitude: 200-400 feet AGL
   > Run-in Heading: 60-90 degrees

   Target: Tank with no reflective surfaces

2. The first step in this evaluation is to evaluate the laser system. Appendix A lists the following information about the PAVE SPIKE system:

   Wavelength: 1064 nm
   ANSI Class: 4
   Single Pulse NOHD: 5807 m
   Multiple Pulse NOHD: 10406 m
   OD required: 4.02
   Buffer Angle: 2.5 mrad
   Beam Divergence: .35 mrad

From this information we see that the laser is not eye safe; eye protection required to view the laser radiation safely must have an OD of 4.02 at 1064 nanometers, the hazard distance for most conditions is 10406 meters, the aiming accuracy allows a 2.5 milliradian buffer angle (rather than 5 milliradians), and the beam divergence is 0.35 milliradians.

3. The range is shown on Figure E.10. Note that the ground is not flat. This will require an extra evaluation step.

4. The target location is also shown on Figure E.10. From the given information we know that it has no reflective surfaces. The target altitude is 2,900 feet MSL.

5. The given mission information was an attack from a run-in heading of 60-90 degrees, a range of 1-4 nautical miles, and the altitude will be 200-400 feet above ground level reference to the target. Figure E.11 outlines the run-in heading and target location.

6. To determine the LSDZ area we must determine how large the laser beam is when it strikes the ground for all flight profile conditions. For this evaluation, we had to produce an additional footprint table (Table E.1) in addition to the ones in Appendix D because the lasing altitudes (target altitude, MSL, plus aircraft altitude, AGL) exeed one km MSL. It was produced with the Z-100/PC compatible program available from USAFOEHL. It includes
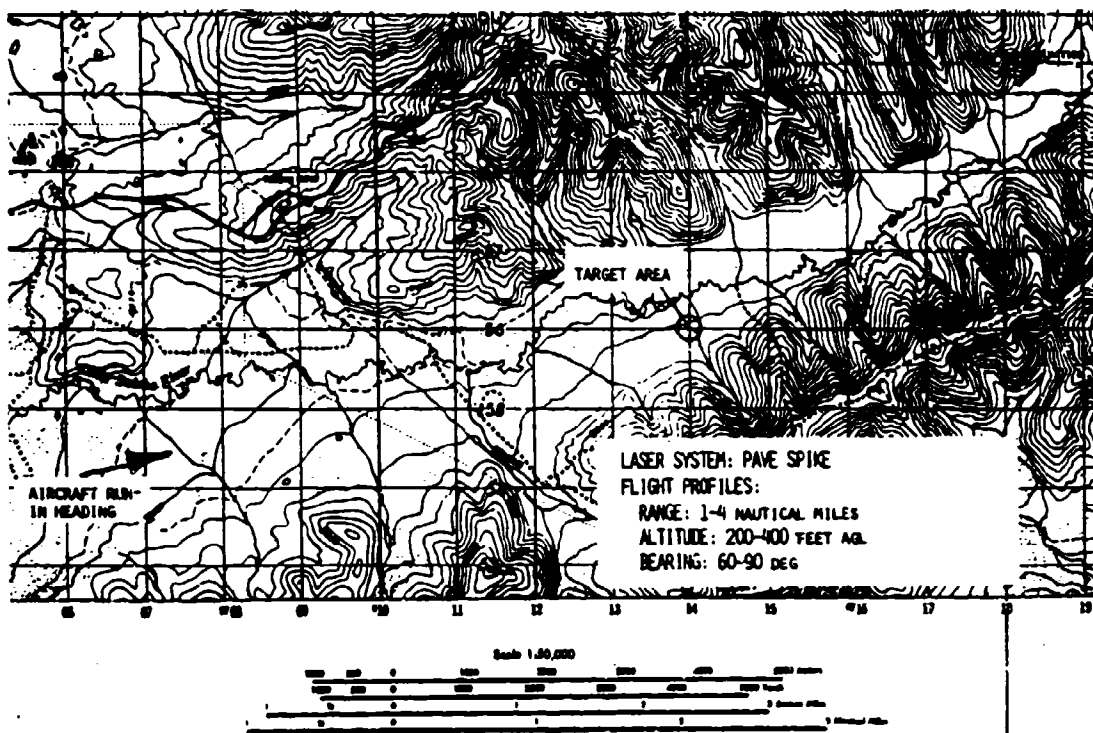
Figure E.10 Laser Range and Target Area
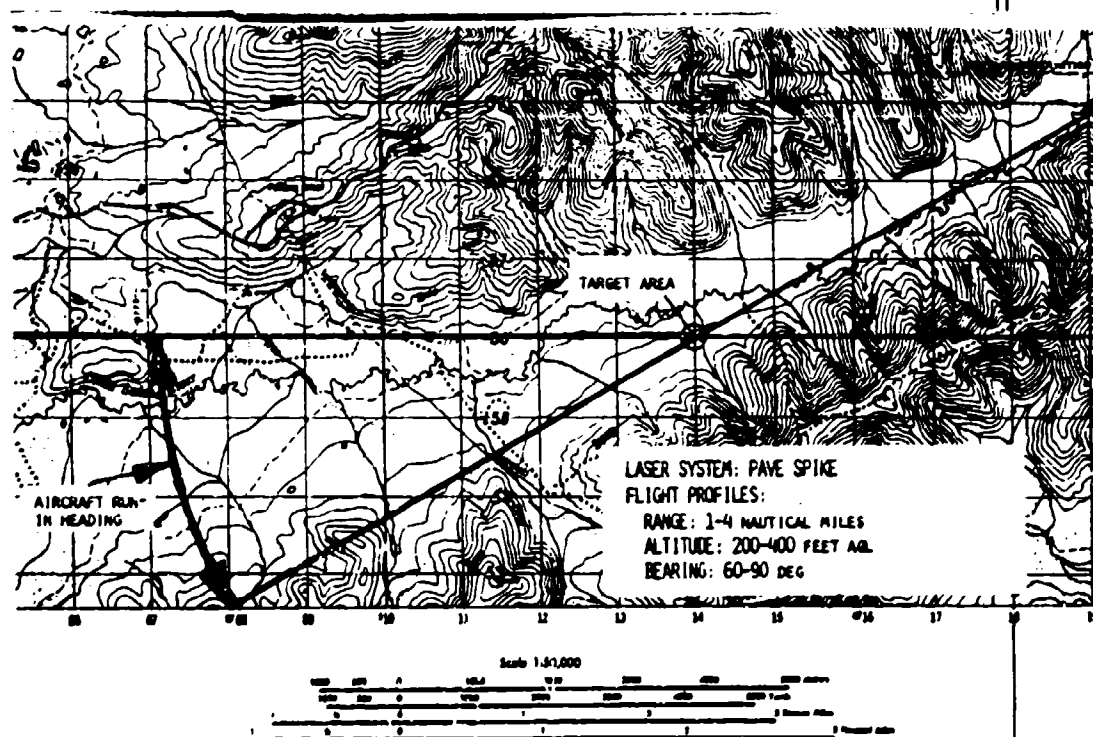
Figure E.11 Attack Headings

atmospheric attenuation and lasing altitudes (MSL). Lasing altitudes are calculated by the program by adding the target altitude (MSL) to each aircraft altitude (AGL reference to the target altitude).

7. Footprint Table E.1. shows the largest footprint dimension for the given flight profiles for each case as follows:

Footprint	Excluding Atmospheric Attenuation	Including Atmospheric Attenuation
Forward	2990 m	1790 m
Aft	1820 m	1820 m
Width	40 m	40 m

From this information we see the effects of atmospheric attenuation. Note that the largest forward dimension is usually produced for the lowest altitude and the longest slant range. Also note for Table E.1. where the NOHD is reduced, the largest forward footprint dimension is not produced at the longest slant range. This is because the forward footprint dimension is truncated by the length of the NOHD at the longest slant range. This concept is further explained in Appendix C. Also note that the sum of the slant range and forward footprint length is approximately equal to the NOHD at low altitudes. From these footprint dimensions, we can draw the outline of the LSDZ based on flat terrain. These areas are drawn on Figure E.12 showing the effect atmospheric attenuation has on these evaluations.
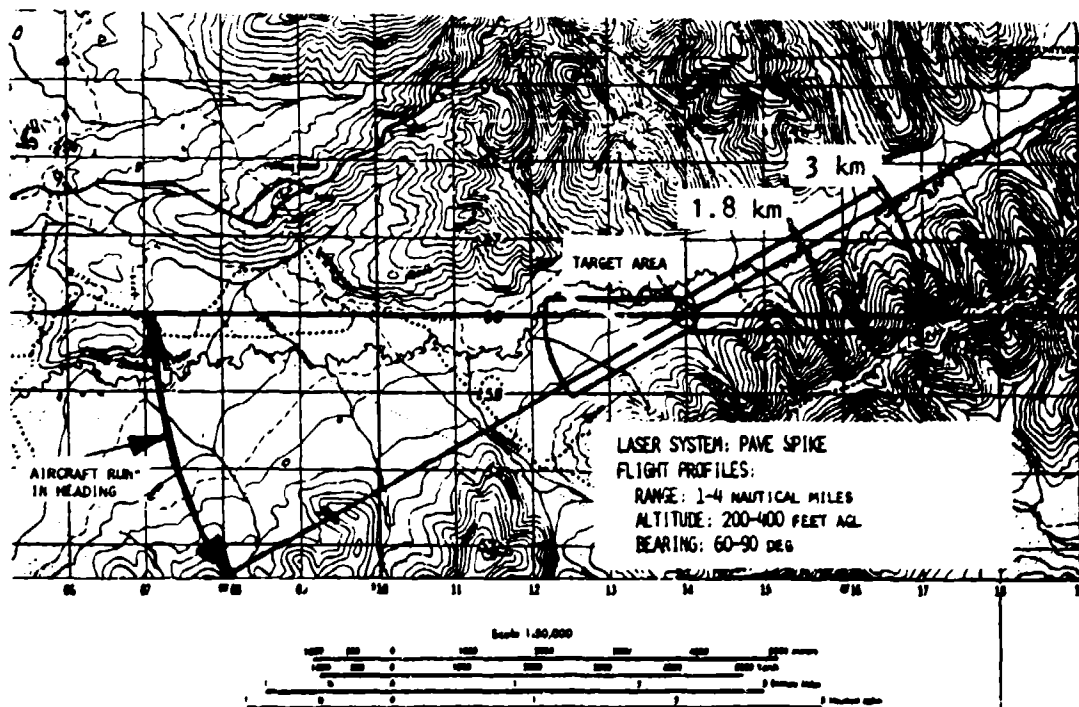
Figure E.12   Initial LSDZ Outline

8. The area outlined by the two pie-shaped sections would be the LSDZ for
flat terrain. Since the ground is not flat, we must determine if the laser
beam actually hits this area and if any other areas are hit. To do this we
determine the height of the laser beam at all distances from the aircraft out
to the NOHD and compare it to the ground elevation as explained in the text of
this report and in Appendix C. Then we adjust the size of the LSDZ to account
for the effects of terrain. In our example, the mountains behind the target,
at bearings of approximately 70-90 degrees, are taller than the highest
portion of the laser beam and therefore terminate the beam prior to reaching
the length of the LSDZ based on flat terrain. The point where the beam is
terminated is found by first finding the height of the top of the buffer zone
at the target. This is approximately half the footprint width or 20 m AGL.
This height is compared to the terrain height near the target. For distances
beyond the target, this height is reduced by the slope of the lowest lasing
angle which is approximately 200 feet for each four nautical miles. At 2 km
beyond the target, the height is 66 minus 50 or 16 feet AGL reference to the
target elevation. From 60-70 degrees the ground is not high enough to
terminate the laser beam nor low enough to extend it. Since the ground in the
aft section of the LSDZ is approximately the same height as the target, the
LSDZ will be the area determined for flat terrain. Additionally, a ridge
about five km from the target in the lower portion of the map is a possible
area of concern. It intersects the possible area that the laser beam may pass
for the given flight profiles. It may be appropriate to include this area as
part of the LSDZ but may also be excluded. In actual practice it is really of
little concern because when the laser beam could strike the ridge, the pilot
could not see the target and therefore should not be lasing. Figure E.13
shows the result of this evaluation. The double hatched area is the
additional area needed for the LSDZ if the value of the NOHD in a vacuum were
used rather than the NOHD including atmospheric attenuation. In practice you
would use the NOHD including atmospheric attenuation if it was available and
not have two areas. Both are shown here to display the difference in results
of including or not including atmospheric attenuation.

9. The LSDZ determined above should be cleared of specularly reflective
surfaces and unprotected personnel. The river must be inspected to see if it
has sections that are very still and could produce hazardous reflections.
This river could also become a hazardous reflective surface when frozen and
smooth. If these conditions exist, the hazardous reflections could extend to
the NOHD, which is beyond the length of this map. This is illustrated in
Figure 13 of the text.

TARGET AREA

LSDZ AREA Z

LASER SYSTEM: PAVE SPIKE
FLIGHT PROFILES:
RANGE: 1-4 NAUTICAL MILES
ALTITUDE: 200-400 FEET AGL
BEARING: 60-90 DEG

AIRCRAFT RUN-
IN HEADING

Scale 1:50,000
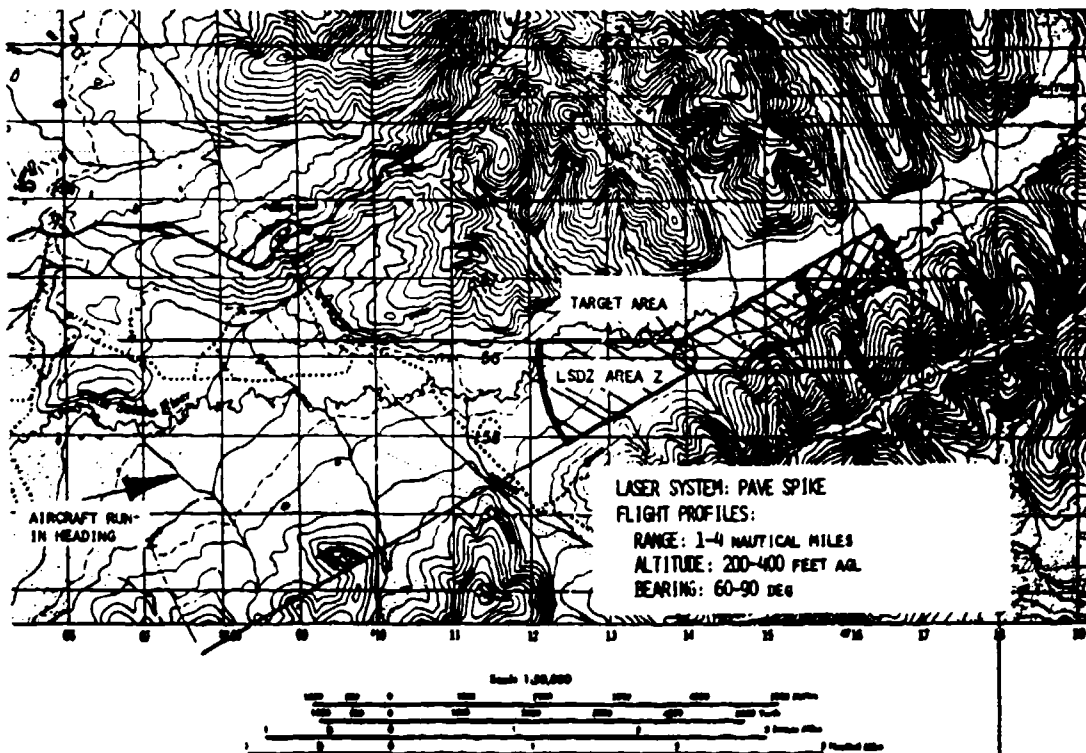
Figure E.13 PAVE SPIKE LSDZ

Table E.1.
LASER FOOTPRINT TABLE for: PAVE SPIKE (INCLUDING ATMOSPHERIC ATTENUATION - TO BE USED WITH RANGE EVALUATION C ONLY)

Table based on: Flat terrain, Buffer= 2.5 mrad, Divergence= .35 mrad
NOMD in vacuum= 10400 meters= 34112 feet= 5.6 nautical miles
OD= 4.02 and target altitude= 2900 feet MSL

Table values are FOOTPRINT dimensions(feet and meters)

SLANT RANGE (nautical miles, feet, and meters)

ALTITUDE (feet)	FOOTPRINT	1.0 NM	2.0 NM	3.0 NM	4.0 NM	5.0 NM	6.0 NM	7.0 NM	8.0 NM	9.0 NM
100	FORWARD	1180 ft	5950 ft	8520 ft	2450 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		359 m	1780 m	2600 m	745 m	0 m	0 m	0 m	0 m	0 m
	AFT	850 ft	2980 ft	5970 ft	9580 ft	13600 ft	18000 ft	22600 ft	27500 ft	32500 ft
		255 m	909 m	1820 m	2920 m	4150 m	5490 m	6900 m	8380 m	9900 m
200	FORWARD	537 ft	2360 ft	5800 ft	2450 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		164 m	713 m	1790 m	745 m	0 m	0 m	0 m	0 m	0 m
	AFT	457 ft	1700 ft	3570 ft	5960 ft	8780 ft	11900 ft	0 ft	0 ft	0 ft
		139 m	518 m	1090 m	1820 m	2680 m	3640 m	0 m	0 m	0 m
300	FORWARD	348 ft	1480 ft	3540 ft	2450 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		106 m	450 m	1080 m	745 m	0 m	0 m	0 m	0 m	0 m
	AFT	312 ft	1190 ft	2550 ft	4330 ft	6480 ft	0 ft	0 ft	0 ft	0 ft
		95 m	362 m	777 m	1320 m	1970 m	0 m	0 m	0 m	0 m
400	FORWARD	257 ft	1070 ft	2530 ft	2600 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		78 m	328 m	771 m	791 m	0 m	0 m	0 m	0 m	0 m
	AFT	237 ft	913 ft	1980 ft	3400 ft	5130 ft	0 ft	0 ft	0 ft	0 ft
		72 m	278 m	604 m	1040 m	1560 m	0 m	0 m	0 m	0 m
500	FORWARD	204 ft	845 ft	1970 ft	3180 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		62 m	258 m	600 m	968 m	0 m	0 m	0 m	0 m	0 m
	AFT	191 ft	742 ft	1620 ft	2800 ft	4250 ft	0 ft	0 ft	0 ft	0 ft
		58 m	226 m	494 m	852 m	1290 m	0 m	0 m	0 m	0 m
600	FORWARD	169 ft	696 ft	1610 ft	2950 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		52 m	212 m	491 m	300 m	0 m	0 m	0 m	0 m	0 m
	AFT	160 ft	625 ft	1370 ft	2380 ft	3620 ft	0 ft	0 ft	0 ft	0 ft
		49 m	190 m	418 m	724 m	1100 m	0 m	0 m	0 m	0 m
	WIDTH	33 ft	65 ft	98 ft	130 ft	163 ft	195 ft	228 ft	260 ft	293 ft
		10 m	20 m	30 m	40 m	50 m	59 m	69 m	79 m	89 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

The footprint table above is based on atmospheric attenuation
reduced NOMD. These are shown in the table below.

ALTITUDE	NOMD(meters)	NOMD(feet)	NOMD(nautical miles)
100	8155.488	26750	4.402567
200	8155.488	26750	4.402567
300	8155.488	26750	4.402567
400	8201.22	26900	4.427255
500	8378.049	27400	4.522712
600	8403.049	27690	4.590191

These are based on OD= 4.02 and target altitude= 2900 MSL

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GROUND TO GROUND MODE, COMPLEX TERRAIN

1. Given: A handheld AN/PAQ-3 MULE Laser System used to designate three targets.

2. The first step in this evaluation is to evaluate the laser system. Appendix B lists the following information about the MULE system:

> Wavelength: 1064 nm
> ANSI Class: 4
> Multiple Pulse NOHD: 20,000 m (79,000 m with optics)
> OD Required: 3.9 (5.8 with optics)
> Buffer Angle: 10 mrad
> Distance S: 200 m

From this information we see that the laser is not eye safe; eye protection required to view the laser radiation safely must have an OD of 3.9 at 1064 nm. The hazard distance for unaided viewing is 20,000 meters and the buffer angle is 10 mrad.

3. The range is shown on Figure E.14. Note the location of the ground based laser station and the three target sites. Also note, the laser is located on a hill over 2000' MSL and the targets are at approximately 1000' MSL. These locations allow the laser beam to be terminated by the ground behind each target.

Figure E.14 Ground to Ground Laser Range
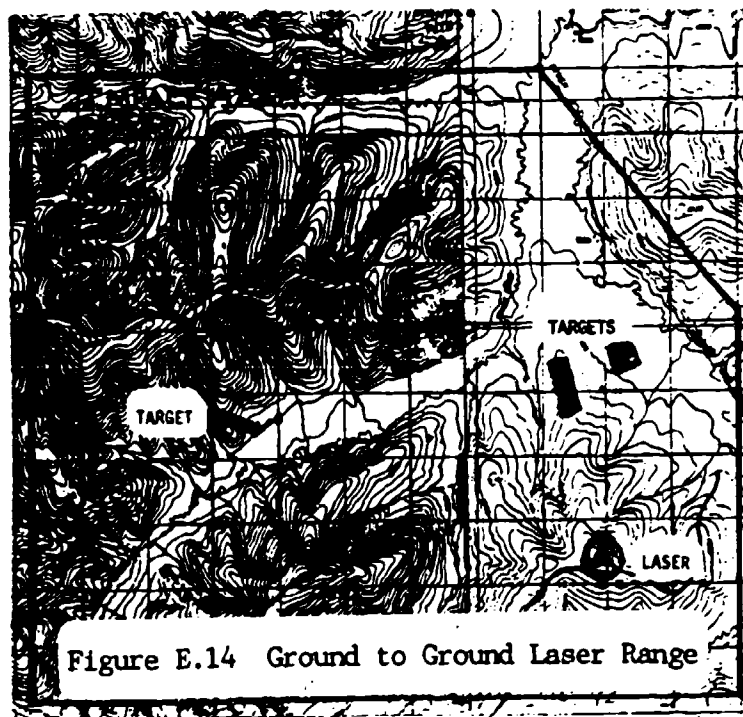
4. Since lasing will be limited to three pre-selected targets, the area for the LSDZ Area Z will only include the zone where the laser will pass while designating these targets. This zone includes every position of the laser on each target plus a 10 mrad buffer angle. If the laser will not be turned off between lasing each target, the area between these targets will be included in the LSDZ Area Z.

5. To determine the LSDZ a separate analysis is done for every target site.

    a. The width of the LSDZ includes the width of the laser beam on any part of the target plus a 10 mrad buffer angle. These regions are shown on Figure E.15 for each target.

    b. All regions within this buffer region and between the laser and target are designated as part of the LSDZ. Regions beyond the target within the buffer zone are also designated as the LSDZ if the distance from the laser is within the 20,000 m NOHD and the laser beam isn't terminated by the terrain.

    c. If laser system elevation is approximately the same as the target elevation, the laser beam should always be fired horizontally. For this situation an adequate back stop would be a hill of a slightly higher elevation. If the target and laser system are at different elevations as in this case, then the slope of the buffered hazard zone must be calculated. Once this slope is evaluated, one may calculate elevations where the beam will intersect the ground and terminate the laser beam.

6. Shown in Figure E.15 is the completed analysis of this range. The LSDZ Area Z is annotated as cross-hatched lined areas. The two targets on the right were combined into one LSDZ because of their proximity. If the operators would not turn off the laser when switching from one target to another, the areas between these two areas would be included in the LSDZ.

Figure E.15 LSDZ for MULE Laser System
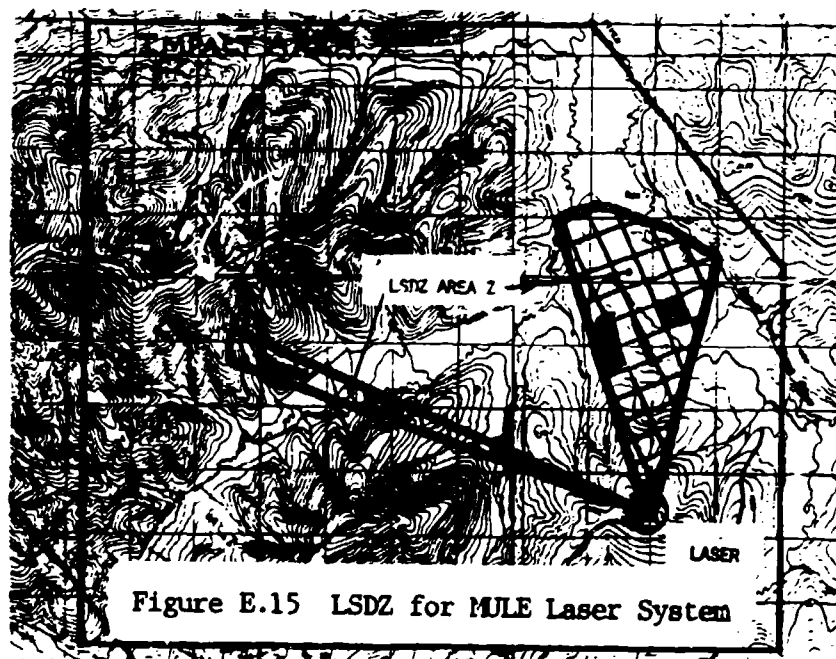
7. The LSDZ Area S is a circle with a radius of 200 meters around each target. This dimension is provided in Appendix B. This area and the backstop areas must be cleared of specular reflections prior to laser operations.

APPENDIX F

DERIVATION OF FOOTPRINT FORMULAS

DERIVATION OF FOOTPRINT FORMULAS

1. The following diagram is used to illustrate the calculations.
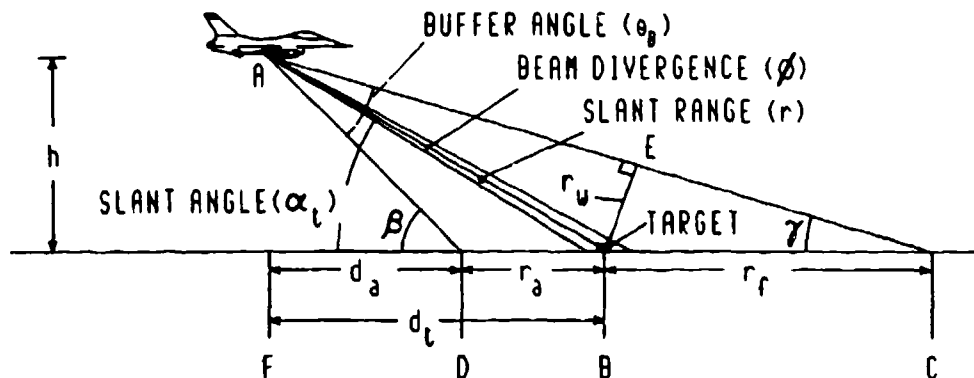
FIGURE F.1. LSDZ WITH SINGLE TARGET

2. Flight profiles are normally specified as range and altitude. We consider the range to be the slant range and have labeled it as r. It is normally given in nautical miles (one nautical mile equals 6076.1155 feet). The altitude can be specified as above ground level (AGL) or above mean sea level (MSL). For our calculations, we must use the altitude above ground level reference to the target altitude. It is normally given in feet. The following derivations are provided to assist you in understanding how we have calculated footprint dimensions.

a. Mathematical Symbols Used

r	=	slant range
h	=	height above ground
d_t	=	horizontal distance from aircraft to target
d_a	=	horizontal distance from aircraft to aft footprint boundry
r_a	=	aft radius of ground hazard
r_f	=	forward radius of ground hazard
r_w	=	the width of one-half of the laser beam plus the buffer angle at distance r
ϕ	=	divergence angle of laser beam (full angle)
θ_B	=	buffer angle of laser beam
α_t	=	slant angle
β	=	angle of aircraft to aft beam radius
γ	=	angle of aircraft to forward beam radius

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b. **Aft Footprint Dimension**

Problem: Find distance r_a in terms of θ, ϕ, r, h

$$r_a = d_t - d_a \tag{1}$$

Solve for d_a-

$$d_a = h/\tan(\beta) \tag{2}$$

where -

$$\beta = \alpha_t + \theta_B + \phi/2 \tag{3}$$

and

$$\alpha_t = \arcsin(h/r) \tag{4}$$

substituting (3) and (4) into (2) gives

$$d_a = h/\tan(\arcsin(h/r) + \theta_B + \phi/2) \tag{5}$$

Solve for d_t -

$$d_t = (r^2 - h^2)^{1/2} \tag{6}$$

substituting (5) and (6) into (1) gives final solution

$$r_a = (r^2 - h^2)^{1/2} - h/(\tan(\arcsin(h/r) \ddagger \theta_B + \phi/2)) \tag{7}$$

c. **Forward Footprint Dimension**

Problem: Find distance r_f in terms of θ, ϕ, r, h

$$r_f = r_w/\sin(\gamma) \tag{8}$$

Solve for r_w -

$$r_w = r \sin(\theta_B + \phi/2) \tag{9}$$

Solve for γ

$$\gamma = \alpha_t - \theta_B - \phi/2 \tag{10}$$

combining (4) and (10) gives

$$\gamma = \arcsin(h/r) - \theta_B - \phi/2 \tag{11}$$

substituting (11) into (8) gives the final solution:

$$r_f = r \sin(\theta_B + \phi/2)/\sin(\arcsin(h/r) - \theta_B - \phi/2) \tag{12}$$

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d. <u>Footprint Width</u>

Problem: Find total width (distance w) in terms of θ, ϕ, r, h

Since w is equal to $2r_w$ (if r_w were rotated about line r, 90°, it would represent half of the elipses width).

Therefore, we can rewrite formula (9) as:

$$w = 2 r\sin(\theta_B + \phi/2)$$

3. The formulas above are fine for most conditions if the footprints are within the NOHD and are on level ground. Exceptions to these formulas are listed below by category:

a. NOHD greater than AC (distance from aircraft to far edge of forward buffer zone): No change, see above.

b. NOHD less than AC and:

(1) Greater than r: Forward footprint length reduced, aft and width dimensions unchanged. This condition normally occurs when the slant range is long and is therefore, approximately equal to d_t. Then:

$$r_f = NOHD - r$$

(2) Less than r but greater than AD: This condition eliminates the forward footprint (the ground is still illuminated by the laser beam but the intensity is below the MPE). Part of the aft footprint exceeds the MPE (the part closest to D). Its shape is dependent on the attack headings and range of flight profiles. Usually, we choose not to reduce r_a, the aft footprint dimension or the width for this condition.

(3) Less than r and less than AD: This condition eliminates the ground hazard zone (all exposures on the ground are below the MPE).

c. Footprint not on level ground (or ground not at same height as target):

A general procedure for this condition is described in the main text of this report. Basically, to determine the footprint size on unlevel ground, the height of the beam and the slope of the extremes of the buffer zone extremes (line AC and AD) must be determined. Then, the AGL referenced to the target is found and compared to the terrain level. The height of the beam is approximately half of the footprint width. Derivation of the slopes of the buffer zone extremes are as follows.

(1) For low slant angles $(r \approx d_t)$

β (slant of AD) $= h/(r - r_a)$

γ (slant of AC) $= h/(r + r_f)$

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APPENDIX G

REFLECTIVITY INFORMATION

REFLECTIVITY INFORMATION

1. When a laser beam hits a surface, three things can happen to the beam. It can be absorbed in the material, transmitted through the material, and reflected off the surface. Reflected laser energy is a major concern on laser ranges. If it is uncontrolled, the potential for eye damage may be greatly increased.

2. Reflective surfaces fall into three categories. These three categories are: diffusely reflective, flat specularly reflective, and curved specularly reflective surfaces. These are illustrated in Figure 1 in the text of this report. Examples of these surfaces are listed in the table below.

    a. The first and of least concern is diffusely reflected surfaces. Reflections from these surfaces are not collimated and essentially spread out according to the inverse square law.

    b. Surfaces that produce specular reflections are the greatest concern. If the surface is flat, the laser beam may just be redirected when it strikes the surface. Usually some of the beams energy is absorbed. The magnitude of the reflected beam is dependent on the reflectivity coefficient of the surface. Typical plate glass will reflect about 8% (4% per surface) of incident light if it is perpendicular to the surface while plastics may reflect more depending on the index of refraction. At near grazing angles, nearly all of the incident energy will be reflected. This is illustrated in Figure G.1. A curve drawn for water would be similar with the reflectivity for normal incidence at two percent and the polarizing angle at 53 degrees. Figure G.2 shows the effect on the reflected beam for the various possible incidence angles.

    c. If the specular surface is not flat, the reflected beam spreads rapidly dependent on the radius of curvature of the surface (for concave reflective surfaces, the beam focuses then spreads). Therefore, they produce hazardous reflections only very near the surface. This is the case with most natural objects. As a general rule, if the laser beam is safe to view for diffuse reflections, it will be safe to view at distances of one meter from curved reflective surfaces such as water droplets and natural foliage.

TYPICAL REFLECTION SURFACES

Diffuse Reflectors	Flat Specular Reflectors	Curved Specular Reflectors
dry foliage	flat glass	wet foliage
rocks	vision viewblocks	beer bottle
camouflage	calm water	turbulent water
soil	vehicle mirrors	glossy paint
matte paint	instrument gauges	optical sights
aluminum cans	flat windows	curved windows
old ordnance	detector windows	automobile bumpers
snow	clean ice	rain drops
	flat chrome	
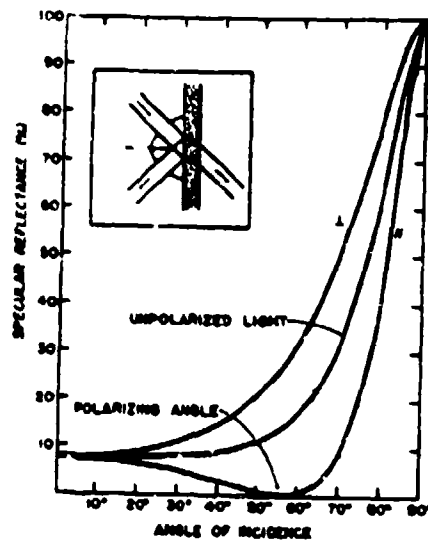
Figure G.1: Specular reflectance from both surfaces of plate glass having an index of refraction of 1.5.
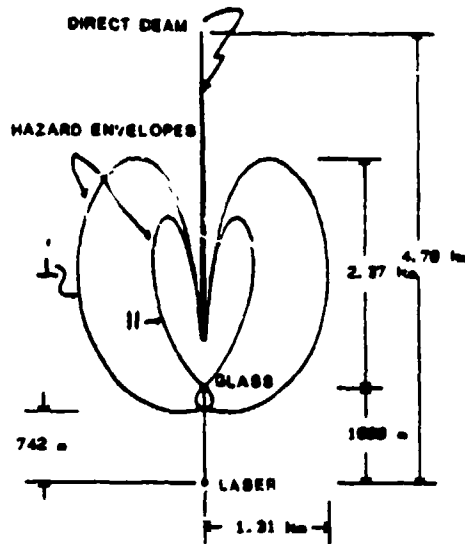
Figure G.2: Hazard envelopes created by a laser beam incident upon a vertically oriented flat (30 cm x 15 cm) glass surface.

3. As way of application, if the reflectivity can be determined, this term can be treated as a transmission coefficient in the NOHD formula. An example of the use of this formula is provided in Appendix H.

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APPENDIX H

ATMOSPHERIC EFFECTS

1. Several procedures are available to include the effects of atmospheric attenuation on the NOHD. Ground based lasers have this effect included in their NOHD. For airborne lasers, the simplest is to use the footprint tables which includes these effects. However, they do not apply to all cases. A specific table for your range and conditions can be generated with the USAFOEHL computer program. This program uses atmospheric extinction coefficients for mid latitude, summer, clear day. These coefficients can be modified for your condition. Alternate manual methods are detailed below.

2. A method frequently used to calculate the NOHD including atmospheric attenuation involves calculating the atmospheric attenuation over the range of NOHD in a vacuum, then iteratively recalculating the NOHD including this attenuation, and then recalculating the attenuation over the new NOHD. This process is outlined in the flow chart below.
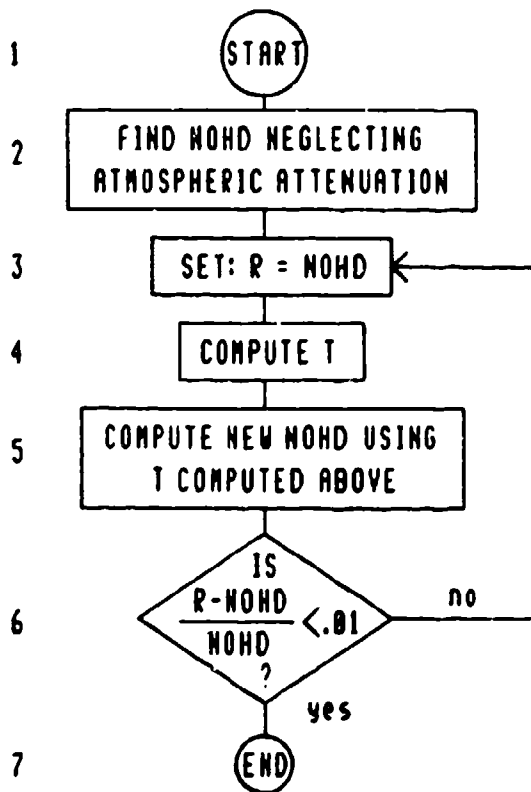
$$NOHD = \frac{(4QT/\pi MPE)^{.5} - a}{\emptyset} \ cm$$

where:

Q = laser energy
T = atmospheric attenuation
MPE = maximum permissible
    exposure limit
a = beam diameter (cm)
$\emptyset$ = beam divergence

$$T = e^{-uR} \quad and \quad u = \sum_{j=1}^{N} u_j R_j$$

where:

u = atmospheric extinction
    coefficient (average)
R = test range (m)
N = # of layers of
    atmosphere
j = atmosphere level

Figure H.1. Atmospheric Attenuation Flow Chart

3. The following example illustrates this procedure:

a. Given: PAVE SPIKE laser system fired from 2000' AGL. The parameters for PAVE SPIKE are as follows:

Wavelength	=	1064 nm
Energy/Pulse	=	168 mJ
Pulse Width	=	0.015 μsec
PRF	=	10 Hz
beam diameter	=	3.59 cm
beam divergence	=	0.35 mrad
Multiple Pulse MPE	=	1.581 E-6 J/cm^2

b. Calculating the NOHD neglecting atmospheric attenuation (step 2) gives:

$$\text{NOHD} = \frac{(4 \times 0.168 \times 1 \, / \, \pi \times 1.581 \text{ E-6})^{\frac{1}{2}} - 3.59}{0.35 \times 10^{-3}}$$

$$= 1040700 \text{ cm}$$

c. Table H.1 gives atmospheric extinction coefficients (μ) for various wavelengths and altitudes. For our case μ is equal to 5.89 E-7 cm^{-1}.

d. By setting R = NOHD (step 3) and calculating T (step 4) gives:

$$T_{\lambda,R} = e^{-(5.89 \text{ E-7})(1040700)}$$
$$= 0.542$$

e. The new NOHD (step 5) including this factor gives

$$\text{NOHD} = \frac{(4 \times 0.168 \times 0.542 \, / \pi \times 1.581 \text{ E-6})^{\frac{1}{2}} - 3.59}{0.35 \times 10^{-3}} \text{ cm}$$

$$= 763,450 \text{ cm}$$

f. Step 6 shows this solution needs further refinement.

g. The following iterations gives these results

T	NOHD (m)
0.638	8290
0.614	8130
0.619	8169

h. The last result is within ten percent of the previous, therefore, it will be used as the NOHD including atmospheric attenuation. We rounded off this value and the NOHD in a vacuum for the tables in Appendix D.

TABLE H.1. ATMOSPHERIC EXTINCTION COEFFICIENTS*

Extinction Coefficients μ(cm^{-1})
Midlatitude Summer - Clear Day (23 km Visibility)

WAVELENGTH

H(km)	337.1 nm	488.0 nm	514.5 nm	632.8 nm	694.3 nm	860 nm	1.06 μm	1.536 μm	3.392 μm	10.591 μm	27.90 μm	337.0 μm
0-1	3.72 E-6	1.95 E-6	1.80 E-6	1.46 E-6	1.96 E-6	1.07 E-6	8.88 E-7	6.67 E-7	1.66 E-5	3.68 E-4	3.00 E-4	2.03 E-4
1-2	2.39 E-6	1.35 E-6	1.26 E-6	9.85 E-7	1.40 E-6	7.18 E-7	5.89 E-7	4.50 E-7	1.81 E-5	3.32 E-4	3.00 E-4	1.60 E-4
2-3	1.39 E-6	6.69 E-7	6.11 E-7	4.58 E-7	7.10 E-7	3.22 E-7	2.60 E-7	1.89 E-7	1.71 E-5	1.91 E-4	3.00 E-4	9.66 E-5
3-4	9.68 E-7	3.62 E-7	3.23 E-7	2.21 E-7	3.63 E-7	1.43 E-7	1.14 E-7	8.16 E-8	1.63 E-5	1.16 E-6	3.00 E-4	5.58 E-5
3-4	7.31 E-7	2.33 E-7	2.08 E-7	1.36 E-7	1.92 E-7	7.49 E-8	5.67 E-8	3.93 E-8	1.60 E-5	7.64 E-7	3.00 E-4	2.87 E-5
4-5	6.42 E-7	1.83 E-7	1.57 E-7	9.19 E-8	1.19 E-8	5.08 E-8	3.74 E-8	2.34 E-8	1.54 E-5	5.58 E-7	3.00 E-4	1.50 E-5
5-6	5.64 E-7	1.33 E-7	1.31 E-7	7.39 E-8	7.96 E-8	3.92 E-8	2.81 E-8	1.67 E-8	1.54 E-5	4.90 E-7	3.00 E-4	7.17 E-6
6-7	5.01 E-7	1.33 E-7	1.31 E-7	6.82 E-8	6.11 E-8	3.27 E-8	3.32 E-8	1.53 E-8	1.46 E-5	3.77 E-7	3.00 E-4	3.97 E-6
7-8	4.54 E-7	1.23 E-7	1.05 E-7	5.91 E-8	5.30 E-8	3.12 E-8	2.24 E-8	1.48 E-8	1.52 E-5	3.04 E-7	2.99 E-4	2.17 E-6
8-9	4.12 E-7	1.14 E-7	9.70 E-8	5.59 E-8	4.77 E-8	3.02 E-8	2.18 E-8	1.43 E-8	1.41 E-5	2.40 E-7	1.32 E-4	1.12 E-6
9-10	3.72 E-7	1.04 E-7	8.92 E-8	5.20 E-8	4.35 E-8	2.65 E-8	2.08 E-8	1.40 E-8	1.43 E-5	1.97 E-7	5.77 E-5	5.72 E-7
10-11	3.35 E-7	9.51 E-8	8.17 E-8	4.81 E-8	3.98 E-8	2.68 E-8	1.97 E-8	1.33 E-8	1.40 E-5	1.59 E-7	2.33 E-5	2.75 E-7
11-12	3.08 E-7	8.79 E-8	7.59 E-8	4.55 E-8	3.75 E-8	2.60 E-8	1.99 E-8	1.31 E-8	1.39 E-5	1.26 E-7	5.87 E-6	8.43 E-8
12-13	2.74 E-7	8.11 E-8	7.04 E-8	4.30 E-8	3.55 E-8	2.90 E-8	1.88 E-8	1.28 E-8	1.57 E-5	9.73 E-8	1.16 E-6	2.05 E-8
13-14	2.63 E-7	7.33 E-8	6.38 E-8	3.95 E-8	3.28 E-8	2.34 E-8	1.76 E-8	1.21 E-8	1.34 E-5	8.92 E-8	2.78 E-7	5.44 E-9
14-15	2.14 E-7	6.98 E-8	5.76 E-8	3.64 E-8	3.04 E-8	2.19 E-8	1.68 E-8	1.16 E-8	1.36 E-5	8.88 E-8	1.28 E-7	2.90 E-9
15-16	1.89 E-7	5.89 E-8	5.17 E-8	3.32 E-8	2.79 E-8	2.04 E-8	1.57 E-8	1.08 E-8	1.28 E-5	8.64 E-8	8.51 E-8	1.64 E-9
16-17	1.69 E-7	5.36 E-8	4.74 E-8	3.10 E-8	2.62 E-8	1.94 E-8	1.51 E-8	1.05 E-8	1.20 E-5	8.53 E-8	6.37 E-8	1.23 E-9
17-18	1.51 E-7	4.93 E-8	4.38 E-8	2.92 E-8	2.90 E-8	1.87 E-8	1.45 E-8	1.02 E-8	1.14 E-5	8.63 E-8	4.67 E-8	9.03 E-10
18-19	1.33 E-7	4.35 E-8	3.67 E-8	2.61 E-8	2.23 E-8	1.67 E-8	1.31 E-8	9.23 E-9	1.09 E-5	8.70 E-8	3.84 E-8	7.30 E-10
19-20	1.15 E-7	3.34 E-8	3.14 E-8	2.09 E-8	1.78 E-8	1.33 E-8	1.04 E-8	7.26 E-9	1.00 E-5	9.04 E-8	3.18 E-8	5.69 E-10

*McClatchey, R. A.; Fenn, R. W.; Selby, J. E. A.; Volt, F. E.; and Garing, J. B. (1972) Optical Properties of the Atmosphere (Third Ed), AFCRL-72-0497, ERP 411.

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4. An alternate approach suitable for computer application has recently been developed. The first step is to calculate the atmospheric attenuation at increments of distance and compare the attenuation with the OD required for a specific laser system at each distance increment. Then, find at what distance the atmospheric attenuation is equal to the OD required. This distance is the NOHD including the effects of the atmosphere. This procedure has been incorporated into the USAFOEHL footprint computer program.

5. Formulas used to calculate the OD and attenuation are provided in AFOSH Standard 161-10. Unfortunately many system parameters are needed, which may be classified. However, it is possible to express these formulas in terms of NOHD, OD, extinction coefficient (μ), and range. These formulas, provided below, allow you to calculate the atmospheric attenuation and OD without using classified parameters. The derivation is left to the reader. Each is expressed as a logrithmic value for easy comparison.

$$OD(r) = \log_{10}\left[10^{OD}\left(1 + (r/NOHD)\left(\sqrt{10^{OD}}-1\right)\right)^{-2}\right]$$

Equivalent Optical Density due to Atmospheric Attenuation $(r) = \log_{10}\left[e^{100\mu r}\right]$

where μ is expressed in cm^{-1} and distance, r is expressed in meters.

6. The following example illustrates the procedure discussed above.

   a. Given: PAVE SPIKE laser system, fired from 2000' AGL at a target 400' MSL.

   b. From the previous example we know the NOHD in a vacuum is 10,400 m and the OD required at the operators is 4. From table H.1, we see the atmospheric extinction coefficient is 5.89 E-7 cm^{-1}

   c. To find the distance where the OD of the atmosphere is equal to the OD required by the laser at a distance, insert the NOHD excluding atmospheric attenuation and the OD required at the aperture into the formulas given in paragraph 4 above. Then, use these formulas at various ranges to find when they are equal. The table below lists several attempts at "guessing" the correct distance.

r	OD	Atmospheric OD
0	4	0
10407	1.035E-07	.266
9000	.124	.230
8000	.225	.204
8100	.125	.207
8200	.204	.209
8150	.209	.208

d. The first two lines confirm the formulas are correct at the aperture and that zero OD is required at the NOHD. The succeeding guesses appoach the NOHD when the two ODs are close. This result is close to the previous example. This result was rounded off and used in the tables at Appendix D. It was also calculated by the USAFOEHL computer program and is shown in Table E.1.

7. Table H.2. provides the approximate reduction in NOHD for 1064 nm lasers when used below one kilometer in altitude (MSL). It is based on an atmospheric extinction coefficient of 5×10^{-7} cm^{-1}.

8. This table would reduce the PAVE SPIKE NOHD to include atmospheric attenuation to approximately 8200 m, which is close to the two previous examples.

Table H.2. Table to Reduce NOHD for Atmospheric Attenuation (units of kilometers)

NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD
0.10	0.10	4.80	4.31	9.50	7.81	52.00	26.70	99.00	38.10	560.00	78.60
0.20	0.20	4.90	4.39	9.60	7.88	53.00	27.00	100.00	38.30	570.00	79.00
0.30	0.30	5.00	4.47	9.70	7.95	54.00	27.30	110.00	40.20	580.00	79.50
0.40	0.40	5.10	4.55	9.80	8.02	55.00	27.60	120.00	42.00	590.00	79.90
0.50	0.49	5.20	4.63	9.90	8.09	56.00	27.90	130.00	43.70	600.00	80.40
0.60	0.59	5.30	4.71	10.00	8.20	57.00	28.20	140.00	45.20	610.00	80.80
0.70	0.69	5.40	4.79	11.00	8.90	58.00	28.50	150.00	46.70	620.00	81.30
0.80	0.78	5.50	4.87	12.00	9.50	59.00	28.80	160.00	48.10	630.00	81.70
0.90	0.88	5.60	4.95	13.00	10.10	60.00	29.00	170.00	49.40	640.00	82.10
1.00	0.98	5.70	5.03	14.00	10.70	61.00	29.30	180.00	50.70	650.00	82.50
1.10	1.07	5.80	5.11	15.00	11.30	62.00	29.60	190.00	51.90	660.00	83.00
1.20	1.17	5.90	5.18	16.00	11.90	63.00	29.90	200.00	53.10	670.00	83.40
1.30	1.26	6.00	5.26	17.00	12.50	64.00	30.10	210.00	54.20	680.00	83.80
1.40	1.35	6.10	5.34	18.00	13.00	65.00	30.40	220.00	55.30	690.00	84.20
1.50	1.45	6.20	5.41	19.00	13.50	66.00	30.70	230.00	56.30	700.00	84.60
1.60	1.54	6.30	5.49	20.00	14.10	67.00	30.90	240.00	57.30	710.00	84.90
1.70	1.63	6.40	5.57	21.00	14.60	68.00	31.20	250.00	58.30	720.00	85.30
1.80	1.72	6.50	5.64	22.00	15.10	69.00	31.40	260.00	59.20	730.00	85.70
1.90	1.82	6.60	5.72	23.00	15.60	70.00	31.70	270.00	60.10	740.00	86.10
2.00	1.91	6.70	5.80	24.00	16.10	71.00	31.90	280.00	61.00	750.00	86.40
2.10	2.00	6.80	5.87	25.00	16.50	72.00	32.20	290.00	61.80	760.00	86.80
2.20	2.09	6.90	5.95	26.00	17.00	73.00	32.40	300.00	62.60	770.00	87.10
2.30	2.18	7.00	6.02	27.00	17.50	74.00	32.70	310.00	63.50	780.00	87.50
2.40	2.27	7.10	6.10	28.00	17.90	75.00	32.90	320.00	64.20	790.00	87.90
2.50	2.36	7.20	6.17	29.00	18.30	76.00	33.20	330.00	65.00	800.00	88.20
2.60	2.45	7.30	6.24	30.00	18.80	77.00	33.40	340.00	65.70	810.00	88.50
2.70	2.53	7.40	6.32	31.00	19.20	78.00	33.60	350.00	66.50	820.00	88.90
2.80	2.62	7.50	6.39	32.00	19.60	79.00	33.90	360.00	67.20	830.00	89.20
2.90	2.71	7.60	6.47	33.00	20.00	80.00	34.10	370.00	67.80	840.00	89.50
3.00	2.80	7.70	6.54	34.00	20.40	81.00	34.30	380.00	68.50	850.00	89.90
3.10	2.88	7.80	6.61	35.00	20.80	82.00	34.60	390.00	69.20	860.00	90.20
3.20	2.97	7.90	6.68	36.00	21.20	83.00	34.80	400.00	69.80	870.00	90.50
3.30	3.06	8.00	6.76	37.00	21.60	84.00	35.00	410.00	70.50	880.00	90.80
3.40	3.14	8.10	6.83	38.00	22.00	85.00	35.20	420.00	71.10	890.00	91.10
3.50	3.23	8.20	6.90	39.00	22.30	86.00	35.40	430.00	71.70	900.00	91.50
3.60	3.31	8.30	6.97	40.00	22.70	87.00	35.70	440.00	72.30	910.00	91.80
3.70	3.40	8.40	7.04	41.00	23.00	88.00	35.90	450.00	72.80	920.00	92.10
3.80	3.48	8.50	7.11	42.00	23.40	89.00	36.10	460.00	73.40	930.00	92.40
3.90	3.57	8.60	7.19	43.00	23.70	90.00	36.30	470.00	74.00	940.00	92.70
4.00	3.65	8.70	7.26	44.00	24.10	91.00	36.50	480.00	74.50	950.00	93.00
4.10	3.73	8.80	7.33	45.00	24.40	92.00	36.70	490.00	75.00	960.00	93.30
4.20	3.82	8.90	7.40	46.00	24.80	93.00	36.90	500.00	75.60	970.00	93.60
4.30	3.90	9.00	7.47	47.00	25.10	94.00	37.10	510.00	76.10	980.00	93.90
4.40	3.98	9.10	7.54	48.00	25.40	95.00	37.30	520.00	76.60	990.00	94.10
4.50	4.07	9.20	7.61	49.00	25.70	96.00	37.50	530.00	77.10	1000.00	94.40
4.60	4.15	9.30	7.68	50.00	26.10	97.00	37.70	540.00	77.60	2000.00	116.00
4.70	4.23	9.40	7.75	51.00	26.40	98.00	37.90	550.00	78.10	3000.00	126.60

APPENDIX I

SOURCES FOR LASER PROTECTIVE EYE WEAR

Table I.1. LASER EYE WEAR DATA FOR 1060/1064 nm WAVELENGTH

Manufacturer	Type	CAT. No.	PN/Description	OD	LTM	Cost
Energy Tech. Inc.	Spectacle/7400 Series		NDGA-7448-1	14	45	106.00
Energy Tech. Inc.	Goggle/B-Series		LGB Broad Spectrum	4	45	193.00
Energy Tech. Inc.	Goggle/7400 Series		NDGA-7448-1	14	45	106.00
Energy Tech. Inc.	Spectacle/VL Series		NDGA	14	45	106.00
Energy Tech. Inc.	Goggle/A-Series		LGA Broad Spectrum	20	20	193.00
Energy Tech. Inc.	Spectacle/7400 Series		NDGA	14	45	106.00
Energy Tech. Inc.	Goggle/VL Series		VL-NDGA	14	45	106.00
Energy Tech. Inc.	Softie/LGS Series		NDGA	14	45	106.00
Energy Tech. Inc.	Goggle/LGS Series		LGS-NDGA	14	45	106.00
Energy Tech. Inc.	Spectacle/A-Series		7400-A Broad Spectrum	20	20	193.00
Fish-Schurman Corp	Goggle/Spectacle	AL-1060-9	Nd-Doped Glass/YAG	9	63	80.00
Fred Reed Optical Co.	Spectacle/7400 Series		NDGA-7448-1	14	45	106.00
Fred Reed Optical Co.	Spectacle/B- Series		7400-B Broad Spectrum	4	45	193.50
Fred Reed Optical Co.	Goggle/VL Series		VL-NDGA	14	45	106.50
Fred Reed Optical Co.	Goggle/CL Series		CL-NDGA	14	45	98.00
Fred Reed Optical Co.	Goggle/A-Series		LG-A Broad Spectrum	20	20	193.00
Fred Reed Optical Co.	Spectacle/A-Series		7400-A Broad Spectrum	20	20	193.50
Fred Reed Optical Co.	Goggle/LGS Series		LDS/NDGA	14	45	106.50
Fred Reed Optical Co.	Goggle/B-Series		LGS-B Broad Spectrum	4	45	193.50
Fred Reed Optical Co.	Goggle/LGS Series		LGS/NDGA	14	45	106.50
Glendale	Goggle/LGS Series	2200	LGS/NDGA	14	45	106.59
Glendale	Spectacle/7400 Series	2205	NDGA-7448-1	14	45	106.00
Glendale	Spectacle/A Series	2193	7400-A Broad Spectrum	20	20	193.00
Glendale	Goggle/A Series	2198	LGA Broad Spectrum	20	20	193.00
Glendale	Spectacle/B Series	2197	7400-Broad Spectrum	4	45	193.00
Glendale	Goggle/B Series	2199	LGB Broad Spectrum	4	45	193.00
Glendale	Spectacle/VL Series	2183	VL-NDGA	14	45	106.00
Physitec	Eye Shield	04-0058	Nd-YAG	7	70	335.00
Physitec	Eye Shield	04-0054	Nd-YAG (Pulsed, Q-Switched)	8		495.00
Physitec	Eye Shield	04-0059	Nd-YAG (CW,Pulsed,Q-Switched)	8	80	345.00
Rockwell Assoc. Inc.	Spectacle-Glass Filter	YAG:LEPD-13-S	Nd-YAG	>4		120.00
Rockwell Assoc. Inc.	Goggle-Glass Filter	YAG:LEPD-13-G	Nd-YAG	4.5		91.00
Rockwell Assoc. Inc.	Spectacle-Glass Filter	YAG:LEPD-13-S	Nd-YAG	>8		140.00
Rockwell Assoc. Inc.	Goggle Glass Filter	YAG:LEPD-13-G	Nd-YAG	>4.5		111.00
US Laser Corp.	Goggle	USL-1075-1	Nd-YAG/ND-Glass Lasers	>6	60	83.00

KEY:

LTM - Luminous Transmission
OD - Optical Density
Cat. No. - Catalog Number

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Table I.2. MILITARY STOCK LISTED EYE WEAR

Type	Stock No.	Manufacturer	Federal Supply Code	P/N	Cost
Ground Crew	4240-00-620-0054	Glendale	16561	LGS-NDGA	73.33
Air Crew	1680-01-169-3151		(MIL-S-8550) No FSC avail.	KG-3 Lens	96.00

EDU-1/P Neodymium Laser Protective Spectacles with Corrective Lenses

The base optometrist shall prepare a DD Form 771 indicating the required refraction and specifying "Aviation (KG-3)" in "Special Lenses or Frames" block and submitted under cover letter from the Commanding Officer of the squadron or activity. The optometrist shall sign DD Form 771 in the "Prescribing Officer" block and the Commanding Officer of the squadron or activity shall sign "Approving Authority" block.

Forward the letter and DD Form 771 to:

>   Commanding Officer
>   NOSTRA
>   Yorktown VA 23691

Provide an information copy without the enclosure to Code 60B1, Naval Air Development Center, Warminster PA 18974-5000.

EDU-1 Neodymium Laser Protective Spectacles with Plano Lenses

>   NSN 1RD 1680-01-169-3151LX $96.00
>   Part # 1368AS101-1
>   Aviation Supply Office
>   700 Robbins Avenue
>   Philadelphia PA 19111
>
>   AUTOVON 442-4360

EEK-3/P Neodymium Laser Protective Visors

>   NSN 1RD 8475-01-115-1711LX $180.00
>   Part # 765AS310-2
>   Aviation Supply Office
>   700 Robbins Avenue
>   Philadelphia PA 19111
>
>   AUTOVON 442-4361

APPENDIX J

DEFINITIONS

DEFINITIONS

The following terms are not found in AFOSH Standard 161-10 and are therefore included in this guide.

Footprint - The area on the ground where the laser beam will probably hit. This includes the laser beam and a buffer zone.

Laser Class - ANSI classification for lasers.

Laser Surface Danger Zone (LSDZ) - The ground area that requires control during laser operation. Sometimes called the Laser Safety Danger Zone.

LSDZ Area S - That surface area within the LSDZ Area Z where the energy or power level of the laser beam is capable of delivering a specular reflection hazard to the aided or unaided eye. Area S is equivalent to the footprint for elevated laser platforms, such as aircraft, which project a well defined (localized) laser footprint on the range. For ground based lasers that do not project a well defined footprint in the target area, Area S is usually defined by a circle of radius, r, around a target area where r is defined for each laser system based on typical operational parameters. Backstop areas where the energy of the laser is capable of producing a specular reflection hazard are also considered Area S. Area S defines the area in which all spectral reflectors must be removed before lasing may begin, i.e., circular area around targets used by ground emitters, footprints from airborne emitters and backstops where the beam path length is less than the Nominal Occular Hazard Distance (NOHD).

LSDZ Area T - That space (area) within the LSDZ Area Z where the energy or power level of the laser beam is capable of delivering a direct hazard to the skin or a diffuse reflection hazard to the aided or unaided eye. This zone usually extends out distance t from the laser aperature.

LSDZ Area Z - This is the total envelope defined as the LSDZ.

Nominal Occular Hazard Distance (NOHD) - The distance from the operating laser at which the radiant exposure or irradiance within the beam equals the maximum permissible exposure limit (i.e., safe distance from laser).

Nominal Hazard Distance (NHD) - The hazard distance for skin exposure.

APPENDIX K

REFERENCES

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REFERENCES

AFOSH Standard 161-10, Health Hazard Control for Laser Radiation

MIL-STD-1425, 13 Dec 83, Safety Design Requirements for Military Lasers and Associated Support Equipment

AFR 50-46, Weapons Ranges

ANSI Z 136.1 - 1986, American National Standard for the Safe Use of Lasers

Sliney & Wabash, Safety With Lasers and Other Optical Sources, Plenum Press, New York, 1980

APPENDIX L

ABBREVIATIONS

LIST OF ABBREVIATIONS

a	diameter of laser beam
AGL	Above ground level
ANSI	American National Standards Institute
BES	Bioenvironmental Engineering Services
d_a	horizontal distance from aircraft to aft footprint boundry
d_f	horizontal distance from aircraft to target
h	Laser height, AGL
LSDZ	Laser surface danger zone (also LSDZ area S, T, and Z)
MPE	Maximum Permissible Exposure
MSL	Mean Sea Level
NHD	Nominal Hazard Distance
NOHD	Nominal Occular Hazard Distance (also NOHD-S and NOHD-O)
NOTAM	Notice to Airmen
OD	Optical Density
Q	energy of laser pulse
R	range used in atmospheric attenuation calculations
r	slant range
r_a	radius of footprint - aft of target
r_f	radius of footprint - forward of target
r_w	radius of footprint - to the side of target
S	radius of LSDZ Area S for ground based lasers
T	atmospheric attenuation term
t	diffuse reflection hazard distance
w	width of footprint
α_t	slant angle

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β angle of aircraft to aft beam radius

γ angle of aircraft to forward beam radius

θ_B buffer angle

λ wavelength

μ atmospheric extinction coefficient

ϕ beam divergence

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HQ PACAF/SGPB Hickam AFB HI 96853-5300	2

HQ USAFE/SGPB   2
APO New York 09012-5000

USAFSAM/TSK   1
Brooks AFB TX   78235-5301

USAFSAM/EDH   1
Brooks AFB TX   78235-5301

Defense Technical Information Center (DTIC)   2
Cameron Station
Alexandria VA   22319

Each Bioenvironmental Engineer   1

Each Bioenvironmental Engineering Section (including ANG and AFRes)   1

Each member, DoD Laser Systems Safety Working Group   1

END

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